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COAL DEVELOPMENT:

Collected Papers

Volume II

Papers presented at
Coal Development Workshops in
Grand Junction, Colorado
and Casper, Wyoming

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Scott Fisher, Project Coordinator
Dave Books, Technical Editor
Linda Branch and Christy Fischer, Copy Editors

July 1983

INTRODUCTION

The collection of papers contained in these volumes and the parallel Coal Development Workshops held in Grand Junction, Colorado, and Casper, Wyoming, in 1982 are an indication of the seriousness with which the Bureau of Land Management (BLM) views the potential role of coal development in the West. The bureau has been very active in funding of coal development studies and research through its EMRIA (Energy Mineral Rehabilitation Inventory and Analysis) program from 1974 to 1982. Products from these efforts range from coal prelease tract studies, such as Pumpkin Creek and Red Rim, to studies on greenhouse testing of materials for evaluation as topsoil, and publications such as this. The potential impacts of coal development are very real, but with programs and leadership, such as the BLM EMRIA effort, the development of mitigating measures for several of the detrimental impacts can be accomplished.

The reader/audience, as I described it to the authors, includes BLM personnel, largely with natural resource backgrounds, who are responsible for making decisions relating to coal development. Equally important are the young people, both in and out of the academic environment, who may find the volumes interesting and challenging.

The primary objective in the design and implementation of this project was to provide a broad collection of reference papers covering the resource and the socioeconomic actions/reactions related to the development of coal in the Northern Great Plains. It became very apparent early in the developmental stages of the project that a reference containing state-of-the-art information for each subject area identified would constitute a significant contribution for both the specialist and land manager. Currently, much of this type of information is found widespread in the literature and needs constant revision to reflect research findings, actual data, and field applications or reactions. A second objective was to stress the interdisciplinary nature of dealing with resource developments while making a strong case for the development and implementation of land use decisions on a holistic basis. I strongly believe that the ecosystem approach must become the fundamental unit of land management. Parallel to that, socioeconomic concerns have to be extended beyond the corporate dividend, per capita income or venereal disease rates for a county. In reality, man exists as a biological component of the ecosystem. Cèrtainly, his scope of influence encompasses interactions between individuals, social groups, and the groups' economic and related development activities.

This collection of papers represents the work of some of the leading authorities involved in coal devlopment in the Western United States. Inclusion of papers by these authorities in this publication was based on each author's knowledge of his respective field and his ability to express those ideas in a workshop format. Nearly all the authors have had academic as well as field experience in their disciplines. The workshops proved particularily fruitful for these individuals because of the high levels of interchange between the disciplines during the workshops. The discussions carried well into several nights and those ideas are reflected in the content of some of the papers contained in these volumes.

It is my sincere hope that these documents will become the fertile ground for additional reading and professional development in the area of coal development rather than balast to prevent bookshelves from wandering away. Hopefully, with education and high-quality training efforts, the workshops, the land use and resource management decisions in the country will be upgraded. Most importantly, the bottom line is whether individuals care enough about the resources of our country to become knowledgeable and involved in the decision-making process.

Scott Fisher,
Project Coordinator
April 17, 1983

ACKNOWLEDGEMENTS

The insight and programmatic direction for the project via its inclusion in the budgetary process came from the BLM Washington Office--in particular such people as Ron Kuhlman, Lee Koss and Monte Jordan. Herb Runkle, who so ably directed the Denver Service Center Division of Special Studies, made both the project and my involvement possible.

Without the efforts of Dave Books, the excellent Helena-based (Montana) editor, and Linda Branch, formerly Technical Editor in the Division of Special Studies and now in Durango, Colorado, with the BLM, the volumes would not have seen the light of day. An enormous amount of work was done by Christy Fischer of BLM, Division of Resource Systems. She has very ably directed much of the publication efforts during the last part of the project. Valerie Schupbach and Carolyn Tarpley of BLM have put in a significant amount of time typing these volumes. Jeanette O'Neill, also of BLM, has helped with some of the proofing.

In addition, a wide range of individuals have supported the completion of the project. Ron Clark and John Baker salvaged the effort when contract typing became impossible. Faye Leonard handled a myriad of contract work related to the workshops and handbook program. Shirley McCulloch created the covers and most ably helped Christy in cleaning up some of the less than professionally done figures.

I express, once again, very grateful thanks to all those listed above for making completion of the project possible.

Scott Fisher,
Project Coordinator
May 19, 1983

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COAL DEVELOPMENT

AND

ASSOCIATED RESOURCES:

BIOLOGICAL

MICROELEMENTS AND THEIR ROLE IN SURFACE MINE PLANNING

by

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INTRODUCTION

The subject of soil trace elements and their toxicities to plants or animals has produced an abundance of directives from regulatory agencies at both the State and Federal level. For the most part, these regulations or guidelines have been directed toward the detection, identification and determination of the concentration of various elements in overburden and soils. Vast sums of money have been spent by mining companies to comply with regulatory agency requests for this information and by the agencies themselves reading and interpreting the results of the mining companies' analyses.

Unfortunately, information about soil elemental levels and toxicities to plants or animals is very confusing. This confusion has resulted from a number of factors that individually or in combination make interpretation of toxicity studies difficult. In particular, the toxicity of an element to plants may be influenced by the presence or absence of other substances in the soil (e.g., different elements, organic matter, etc.), as well as texture and pH of the soil itself. Plant species or genotype, physiological state, and maturity also control the response of an organism to "toxic" substances. Factors related solely to the element also influence the toxicity of many substances. Pertinent examples include the chemical form or state of the element, and, with respect to animals, the dosage or frequency and duration of intake of the mineral. Thus, the interpretation of the inherent toxicity of an element in the soil cannot be based upon concentration alone but must include a number of other factors.

In this paper I will attempt to clarify some of the questions surrounding interpretation of soil trace element problems. This will facilitate regulatory agency and industry understanding of potential plant toxicities and how they may be addressed. Since regulations were, in general, written for soils or overburden and reflect a concern for terrestrial vegetation primarily and animals only secondarily, this discussion will focus on elemental constituents in plant root zones and in plant tissues. In some cases elemental levels in plants are not hazardous to the plants themselves but are hazardous to herbivores consuming the vegetation. In these instances specific mention will be made of concentrations of the elements that are detrimental to animal consumers or that pose food chain accumulation problems.

WHAT ARE "TRACE" ELEMENTS?

The periodic table contains over 100 elements, but obviously regulatory agencies and the mining industry are not concerned with all of them. However, certain of the naturally occurring elements may be essential or toxic to plants or animals and hence are of direct concern.

Of the known elements, three make up the major portion of all plant or animal tissues: carbon, hydrogen, and oxygen. These are not known to be toxic in natural environments and thus are of no concern in this study. Another six elements are referred to as "macronutrients," which include nitrogen, phosphorus, potassium, calcium, sulfur and magnesium. One or more of these may be added to the soil to stimulate plant growth if the root zone is deficient in these elements. Undesirable effects are produced only if these elements occur in a specific chemical combination (e.g., sulfur dioxide is a toxic gas but organic sulfur in the soil is desirable) or in very large concentrations. The toxic forms of these elements are usually products of our industrialized society; since they are not characteristic of western soils or overburden materials, they will not be included in this paper.

A third group of elements are universally present in soils, plants, and animals, often in very small quantities (parts per million to parts per billion). Of this group, certain elements--"micronutrients"--are necessary for normal plant growth and development. Although considered nutrients, these elements will produce toxic effects if present in soils or animal diets in certain concentrations. These include iron, copper, zinc, manganese, molybdenum, boron, and chlorine. Several other elements have been shown to be essential to one or more species of plants or animals and may be included in this group. These are fluorine, iodine, selenium, sodium, nickel, vanadium, aluminum, chromium, and cobalt. A small group of elements is not believed to have any biotic function and is toxic to plants or animals above vaguely defined levels (threshold concentrations). These include lead, cadmium, mercury, and arsenic. Therefore, for purposes of this paper, trace elements are those elements that are biologically active--i.e., producing desirable or undesirable effects in plants or animals and present in small quantities in soils and plants (Table 1).

Some elements are common in surface soils but have little or no apparent influence upon plant growth (e.g., silicon and barium). Other toxic elements are present in such small quantities in most soils or overburden that they rarely inhibit plant or animal growth and development (Table 2). Most other elements present in trace quantities in soils (e.g., gold, germanium, helium, etc.) are not inherently toxic to plants or animals in concentrations found in natural materials.

TABLE 1. BIOLOGICALLY ACTIVE TRACE ELEMENTS (INCLUDING THEIR ABUNDANCE IN SOILS OF THE GREAT PLAINS (OR OF THE EARTH) AND THEIR POTENTIAL PLANT TOXICITY)

Element	Abundance (ppm)	Toxicity[1]	Comments
Aluminum	4-5%[2]	Moderate to plants	Plant toxicity only occurs at low soil pH, <6
Arsenic	5-12[2]	Moderate to plant, high to mammals	Toxicity related to chemical form
Boron	300-1000[2]	Moderate to plants	Essential plant nutrient
Cadmium	0.1-1	Moderate to plants, higher to animals	Long half-life in animals
Chlorine	100[1]	Slight to plants	Essential plant nutrient
Chromium	30-70[2]	Moderate to very toxic to plants	Cr VI very toxic to plants and animals
Cobalt	7-10[2]	Very toxic to plants	
Copper	15-30[3]	Very toxic to plants	Essential plant nutrient
Fluorine	400-700[2]	Moderate to plants	Toxicity due to air pollution
Iodine	<0.5-1[2]	Slight to plants	No reports of naturally occurring toxicity
Iron	2-5%[3]	Slight to plants	Essential plant nutrient
Lead	5-30[3]	Very toxic to plants	Elevated plant levels generally indicate an air pollution problem from use of lead in gasoline
Manganese	200-500[3]	Moderate to plants	Essential plant nutrient
Mercury	0.02-0.04[2]	Very toxic to higher animals	Volatilizes at soil surface temperatures in temperate regions
Molybdenum	2-4[4]	Slight to plants	Food chain effects on animals are more important than plant toxicity
Nickel	13-40[3]	Very toxic to plants	Toxicity characteristic of serpentine soils
Selenium	<0.1-0.3[2]	Slight to plants	Food chain effects on animals are more important than plant toxicity
Sodium	0.5-1.1%[2]	??	Essential for some plants, toxic to others

TABLE 1. (Cont.)

Vanadium	50-100[2]	Moderate to plants	No reports of toxicity or deficiency in natural environments
Zinc	30-90[3]	Moderate to plants	Essential plant nutrient

[1] Bowen 1966.
[2] Gough and Erdman 1978.
[3] From studies by the author.
[4] Robinson and Alexander 1953.

TABLE 2. TOXIC TRACE ELEMENTS NOT OF CONCERN IN MINESOILS

Element	Abundance (ppm)	Toxicity[1]	Comments
Antimony	2-10[1]	Moderate to all organisms	No reports of natural plant poisoning
Beryllium	1.5-3.0[2]	Very toxic to plants	No reports of natural plant poisoning
Bismuth	<1[1]	Moderate to plants	No reports of natural plant poisoning
Bromine	1-10[1]	Very toxic to plants	Br2 used as herbicide
Silver	0.01-5[1]	Very toxic to plants and animals	AgI used in cloud seeding
Tin	1-2[2]	Very toxic to plants	No reports of natural plant poisoning
Tungsten	<2[1]	Moderate to plants	No reports of natural plant poisoning

[1] Bowen 1966.
[2] Gough and Erdman 1978.

POTENTIAL FOR PLANT TOXICITY

The elements listed in Table 1 all possess an inherent potential to produce toxicity symptoms in terrestrial plants or animals. They have received the attention of researchers for this plus other reasons, but it must not be assumed that all should be monitored in minesoils, topsoil or overburden. Each element must be individually evaluated in terms of its potential to inhibit or stimulate plant growth in the semiarid environment of the Great Plains.

The methods of analysis of soil trace elements are numerous. "Total" elemental concentrations are determined after digestion of the soil sample in a strong acid. "Available" or "extractable" elemental levels refer to the amount of an element removed from the soil by various solutions. In semiarid western soils the extracting agent is usually DTPA (diethylenetriamine-pentacetic). Much research in eastern agricultural soils has been carried out using ammonium acetate as the extracting solution. Many studies of toxic elemental concentrations are undertaken with water as the extracting agent. None of these procedures is comparable and the elements extracted usually do not represent the "available" elemental pool. Relationships between extractable levels and plant elemental concentrations have been established for only those elements of agricultural importance and in many cases these relationships are not appropriate in Northern Great Plains soils.

To produce a plant inhibitory effect (toxic response), a mineral must be absorbed by the plant or interact at the root-soil interface. The total quantity of a toxic substance in the soil is, therefore, not as important as the amount that is "available" to the plant for uptake. Unfortunately, most elemental studies emphasize "total" soil concentrations and thus are of limited value for plant toxicity research. Other studies of elemental inhibitory effects on plants are often conducted in solution cultures. An aquatic root medium does not represent the soil system and the value of such studies to the derivation of plant toxicity concentrations in soils is relative. Nevertheless, with an information base derived from these types of studies and other more pertinent data, a qualified judgment may be made as to the desirability and necessity of trace element analytical determinations in soils and overburden prior to strip mining.

Sodium and Chlorine

Chlorine is an identified plant nutrient (Johnson et al. 1957) and sodium has been described as essential for at least one plant species (Brownell and Wood 1957). Although the toxicity of these elements individually has not been clearly defined, they adversely affect the soil moisture regime long before either expresses a direct toxicity. These problems are adequately covered by soil scientists investigating salt problems in sodic and alkaline soils and will not be considered in this paper.

Fluorine

Fluorine is not an essential plant nutrient. It is a common component of all soils, however, ranging from a few ppm to a few tenths of a percent in natural environments (Shacklette et al. 1974). Fortunately, fluorine is readily complexed by calcium in most soils. This complex is insoluble and not available for plant absorption (Gisiger 1968). Concentrations of this element commonly found in vegetation of the western coal region range from 1 to 4 ppm (Gordon et al. 1976, Munshower et al. 1978). Fluorine levels greater than 10 ppm in vegetation are usually an indication of airborne fluorine pollution and not a soil problem. The absence of a suspect level for this element in State reclamation guidelines is a reflection of its potential to produce a problem in minesoils.

Iodine

This element has not been shown to be essential for plant growth but is necessary in animal diets. Like fluorine, iodine is a component of all soils. Gough and Erdman (1978) reported concentrations in southeastern Montana surface soils of around 1 ppm. This element, although toxic to many plants, does not present a problem in any Great Plains soils because it is not readily available for plant uptake (Martin 1966). Much of the Northern Great Plains is also included in the so-called "goiter belt," a region deficient in vegetative iodine for animal diets (Kubota and Allaway 1972). It is unlikely that this element will present a plant or animal toxicity problem in this region and the absence of any soil or overburden testing program in State regulations is appropriate.

Iron, Aluminum and Manganese

Iron, an essential plant nutrient, has not been reported in toxic soil concentrations under natural conditions. Because of the reduced solubility of this element at pH values above 6.0, it is difficult to define a toxic concentration in western semiarid soils. Inorganic iron in solution reaches a minimum value in the pH range of 6.5 to 8.0. The activity of iron (+2) decreases one-hundredfold for each unit increase in pH, and the activity of iron (+3) decreases one-thousandfold for each unit increase in pH (Lindsay 1972a, 1972b). A toxic iron concentration is, therefore, unlikely to occur in natural environments in the alkaline soils of the Great Plains.

Follett and Lindsay (1970) reported that soil iron concentrations in the 0 to 2 ppm range (as determined by DTPA extracts) were low for plant growth, while concentrations above 4.5 ppm were adequate; but these authors made no mention of a toxicity level. In a study of range soils in southeastern Montana, Munshower et al. (1978) found DTPA extractable iron concentrations in 100 surface soils to range from 3 to 30 ppm and in 25 subsoils to range from 1 to 17 ppm. None of these soils was "toxic" to vegetation. Haby and Sims (1979) reported iron concentrations in 15 bench mark soils and 243 grain producer soils in Montana to range up to 30 ppm. Gough and Seversen (1981) reported on iron concentrations in topsoil and spoils of twelve mines on the Great Plains.

They found seven topsoil samples yielding over 100 ppm and five samples producing between 40 and 100 ppm iron in the ninety samples examined. Unfortunately, they made no statement about vegetative growth in the study sites other than the comment that the sites were seeded. Murphy and Walsh (1972) mentioned a soil with over 5 percent iron without any apparent toxicity problem.

Vegetative iron levels are site- and species-specific. In a study of vegetation in southeastern Montana rangelands, Munshower et al. (1978) found iron concentrations ranging from 30 to 150 ppm in perennial grasses and from 100 to 450 ppm in broadleaf plants. Both plant groups showed growing season variations, with higher concentrations occurring in samples collected in late summer and fall. Plant species growing in minesoils showed higher iron levels than the same species growing on nearby native range (Munshower and Neuman 1978a), although these increases were small (<25%). These elevated iron levels were probably beneficial to grazing animals because of the commonly low levels of iron and other trace nutrients in native range vegetation. Because iron toxicity does not appear to be a problem in soils or vegetation on mined lands of the Great Plains, industry or regulatory personnel should not address significant resources or time to its detection.

There is little evidence that aluminum is an essential plant or animal nutrient even though it is ubiquitous in soils. Its solubility is similar to that of iron; however, unlike iron it can be toxic to plant species rooted in native soils and minesoils. However, in all reported cases of phytotoxicity of this element, the hydrogen ion concentration of the root medium was very high. Two older reports stressed that aluminum availability in soils is very low unless the soil pH is reduced below 4.5 (Magistad 1925, Pierre 1931). Pratt (1965a) suggested that no exchangeable aluminum is likely to be found in soils having pH values above 5.0.

Total aluminum in Great Plains soils may reach 4 percent or more (Severson 1978a, 1978b), but as was pointed out above, available levels of this element in alkaline soils are extremely low. Plant concentrations as reported by Gough and Severson (1981) showed some variation from one mine site to another. In their studies, alfalfa usually revealed several hundred ppm while grasses indicated a few hundred ppm.

Most studies of the toxicity of this element have been conducted in solution cultures at pH values around 4.5. At these hydrogen ion concentrations, aluminum plant toxicity was species-specific. McLean and Gilbert (1927) classified 12 crop plants as to their sensitivity to this element. Barley and lettuce showed injury symptoms at 2 ppm, while redtop (Agrostis alba) did not reveal any sign of injury until the solution contained 14 ppm. Lignon and Pierre (1932) found similar responses to aluminum in their solution culture studies. More recent research has emphasized the importance of calcium and phosphorus interaction with aluminum in the inhibition of plant growth (Long and Foy 1970, Foy and Brown 1964). This research and other related studies indicate that the concentrations of these two plant nutrients have a direct relationship to the toxicity of aluminum.

Because soil pH is rarely a problem in the Great Plains, there are no reports of aluminum toxicity from this region. Aluminum, like iron, does not warrant analysis in minesoils or overburden unless pH values are very low (<5.0). When overburden pH is low, however, it must be handled with care to prevent the deposition of acid materials within plant root zones and the inhibition of minesoil vegetation by aluminum.

Manganese is similar to iron in its importance to plants and animals, and to iron and aluminum with respect to increased activity at low soil pH values. This element exists in several oxidation states that are influenced by pH as well as the oxidation-reduction potential of the soil. In poorly aerated soils (marshes, wet areas), conversion to the more soluble manganous state (Mn^{+2}) takes place. On the Great Plains, toxic concentrations of this element only occur in small, water saturated areas. When these sites are mined, they must be drained, and oxidation of the very soluble manganous ion to less soluble forms begins.

The question of toxicity to range vegetation of even the soluble manganese form must be questioned. Periodically, flooded soils of the Great Plains coal region usually produce lush stands of grasses and shrubs unless salt problems restrict their development. On a site adjacent to a water impoundment on native range, I found willow (Populus spp.) leaves to have manganese concentrations of 1,500 to 3,500 ppm. Concentrations of this element exceeding 1,000 ppm in plant tissues are considered indicative of toxic manganese concentrations in the root medium (Labanauskas 1965). In this periodically flooded area the trees and western wheatgrass (Agropyron smithii) understory were healthy and reproducing abundantly. They showed no inhibitory influence from the elevated manganese levels and were heavily grazed each year with no apparent harm to wildlife or cattle. Normal levels of this element in vegetation of the Great Plains usually range from less than 100 to 200-300 ppm (Munshower et al. 1978, Gough and Severson 1981), considerably lower than the assumed toxic level.

Various studies have found available levels of manganese (DTPA extractable) in soils of the Great Plains to range from less than 1 to 47 ppm (Munshower et al. 1978, Follett and Lindsay 1970, Severson et al. 1978). In a study of manganese toxicity to plants growing in calcareous soils of neutral or high pH (Moraghan 1979), DTPA extractable soil manganese ranged from 11 to 81 ppm. Plant manganese concentrations were poorly related to DTPA-extracted manganese. Because of the low availability of manganese in soils of our region and the questionable toxicity level, this element does not warrant analytical determination in topsoils or overburden.

Chromium and Nickel

The presence of toxic amounts of chromium and nickel in soils derived from ultrabasic rocks has been recorded, but in almost all such cases elevated levels of both elements occurred in the same samples. These soils, referred to as serpentine, are found throughout the world. They are infertile and support a unique flora tolerant of the elevated metal levels. Although serpentine soils have been identified in northwestern North America, none has been found within the confines of the Northern Great Plains.

The importance of chromium for plant growth is being debated, but evidence does not support the necessity of this element to plants at this time (Huffman and Allaway 1973). If a required or beneficial concentration exists, it is extremely low. The value of chromium for animals has been more clearly defined, and it appears that minute quantities in the diet are beneficial (Mertz 1969, Davidson and Blackwell 1968).

Hinkley et al. (1978) and Gough and Erdman (1978) reported total chromium levels in soils of southeastern Montana ranging from 50 to 170 ppm. Chromium concentrations in serpentine soils would be found in the tenth of a percent range or higher (Moore and Zimmerman 1977, Pratt 1965b). It is evident that toxic chromium concentrations are not likely to be found in range soils or overburden of the Great Plains. Furthermore, additions of soluble forms of chromium to soils are reduced to insoluble chromium ($^{+3}$) oxides within a few months (Cary et al. 1977). The remote possibility of toxic concentrations of this metal in overburden on minesoils does not warrant analysis of drill-hole or topsoil samples.

Nickel has commanded much attention from regulatory agencies, mining companies, and scientists. A voluminous literature has been generated on its soil toxicity problems. Fortunately, these problems are restricted to very acid or serpentine soils. No recorded incidences of nickel toxicity in semiarid calcareous soils can be found in the large number of publications related to this topic.

Several experiments have elicited a positive response in animals to small concentrations of nickel in the diet (Nielsen 1974, Spears et al. 1979). However, no data exist to show a desirable plant response to root-medium nickel (Brooks 1980). On the other hand, nickel is regarded as more phytotoxic than many common metals. Hunter and Vergnano (1953) rated the relative abilities of the following elements to produce chlorosis as: nickel>copper>cobalt>chromium>zinc>molybdenum>manganese. The toxicity of nickel, however, is concentration and pH dependent (Hunter and Gergnano 1952). In pot studies using corn, 100 ug Ni/g soil produced no vegetative growth response at pH 7.5 but some growth reduction at pH 4.2 (1.16 vs. 0.96 g dry vegetation/shoot). In the same study, 250 ug Ni/g soil reduced corn growth 72 percent at pH 4.2 and only 47 percent at pH 7.5 (Wallace et al. 1977). Another study found reduced alfalfa production in soil of pH 7.5 with the addition of 500 ppm nickel (Halstead et al 1969).

Two studies of Great Plains minesoils and native range soils revealed total nickel concentrations of 5 to 40 ppm (Munshower et al. 1978, Severson et al. 1978); these investigations covered both surface soils and overburden. Extractable levels (DTPA) in these materials ranged from 0.1 to 2.6 ppm. Because the possibility of toxic levels of this element in soils or overburden of this region is very remote, mining companies should not be required to analyze for this element when soil or overburden pH values are over 6.5.

Cobalt

Cobalt has not been shown to be a growth requirement of any higher plants, but it is essential to nitrogen fixing blue-green algae (Holm-Hansen et al. 1954) and the symbiotic, nitrogen fixing bacteria found in root nodules of higher plants (Reisenauer 1960, Bond and Hewitt 1962). In the form of vitamin B_{12} this element is essential to most animals and especially to ruminants (Beerstecher 1977, Smith and Loosli 1957). Elevated levels of cobalt have been recorded in natural vegetation but only in certain accumulator species (Lazar and Beeson 1956, Yamagata and Murakami 1958). These plants showed no growth inhibition associated with the elevated cobalt levels. Cobalt deficiencies in plants consumed by grazing animals are easily corrected by judicious preparation and use of salt blocks.

Soil cobalt levels are usually very low, ranging from a few to 40 ppm (Swaine 1969, Hinkley et al. 1978), while extractable concentrations reported in the literature are always less than 1 ppm (Severson et al. 1978, Vanselow 1965). Elevated soil levels of this element are only found in serpentine soils or near nickel deposits (Swaine 1969). No toxic concentrations of cobalt have been recorded other than those on serpentine soils or in solution culture studies. The analysis of this element in soils or overburden of Great Plains mine fields is not recommended.

Vanadium

As with many other elements, the essentiality of vanadium for higher plant growth has not been clearly defined (Health Effects Research Laboratory 1977); however, it has been shown to stimulate nitrogen fixation by bacteria in root nodules of leguminous plants (Cannon 1963, Nicholas 1957). Small quantities of this element have been shown to be required for the normal growth and development of two animals--laboratory rats and chickens--and it is assumed to be essential for all animals (Schwarz and Milne 1971, Hopkins and Mohr 1971).

Plant concentrations of vanadium are usually in the range of a few ppm; Gough and Severson (1981) reported concentrations in plants on minesoils of less than 2 ppm. Concentrations of this element in vegetation growing in minesoils or on native range do not appear to pose a threat to animals.

This element is unevenly distributed in the earth's crust in small or very small quantities, usually less than 100 ppm total vanadium (Gough and Erdman 1978, Severson 1978a). There have been no reports of plant damage from elevated soil concentrations of vanadium, and only one episode of animal toxicity, which resulted from a pasture contaminated with soot from a nearby oil fired boiler (Health Effects Research Laboratory 1977). Soil or overburden concentrations of this element are not of sufficient concern to warrant analysis for potential toxicity problems.

Lead and Cadmium

These two elements are considered together because both are metal toxicants produced in abundance by modern society. Neither appears to be required by any organism at any concentration and both have a relatively long half-life in animals. Because of long retention periods, the possibility of chronic animal toxicity levels via food-chain uptake must be evaluated. Plant accumulation from minesoils must, therefore, be investigated within the framework of long-term, chronic pollution problems as well as plant and animal toxicity and water quality considerations. It should be noted that no naturally occurring soil toxicity problem has been recorded for either of these elements. All reported instances of plant or animal poisoning by these metals are related to pollution problems of human origin.

Roots from plants growing in contaminated materials have consistently revealed much higher levels of toxic heavy metals than leaves. Apparently, movement of toxic elements from roots to stems and leaves is restricted by homeostatic mechanisms in the plant. For many years, scientists questioned the movement of any heavy metal toxicants such as lead and cadmium through plant tissues; however, growth chamber and isotope research have clearly shown that these metals are translocated by higher plants from roots to leaves, although in relatively small quantities (Suchodoller 1967). Hemphill (1977) reported that doubling of the leaf lead concentration would require a tenfold increase in soil lead levels. While Marten and Hammond (1966) reported lead additions of this magnitude (10 X) to soils produced no significant effect on brome grass lead levels. When elevated lead levels occur in vegetation (>10 ppm), sources of airborne contamination or soil pollution must be suspect.

Lead is retained in the soil system by precipitation as hydroxides, by formation of insoluble phosphorus compounds or, at higher pH values, by formation of lead carbonate (Jurinak and Santillan-Medrano 1974). None of these forms is readily leached from the profile by water or available to plant roots. In studies of Great Plains soils and overburden, DTPA extraction of lead commonly revealed soil values of 0.2 to 2 ppm (Munshower et al. 1978, Severson et al. 1978) and vegetative concentrations of 1-2 ppm in this relatively unpolluted area (Munshower et al. 1978, Gough and Severson 1981). To double plant lead levels would require DTPA extractable soil lead concentrations equivalent to Montana's published suspect levels for this element (10 X present levels; Harrington 1977). Yet, vegetation lead levels greater than 30 ppm may be consumed by horses (which are more sensitive to lead poisoning than cattle) for prolonged periods without any measurable undesirable effects (Simpson and Damron 1970). If soil lead levels 10 times greater than those reported in Great Plains soils will not produce vegetation toxic to sensitive animals or pollute ground or surface waters, the basis for suspect levels must be questioned.

The possibility of soil lead inhibition of seed germination or plant growth exists; however, concentrations required to elicit such responses are very large (Holl and Hampp 1975). The contaminated but vegetated soils adjacent to highways and near the lead smelter at East Helena, Montana, support this point (Lagerwerff and Specht 1970, EPA 1972). These areas, which have total soil lead concentrations of 500-1000 ppm, support apparently normal vegetation.

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Severson et al. (1978) did not publish the percent of total soil lead extracted by DTPA in their studies but my investigations have indicated that 5 to 12 percent of total lead in undisturbed alkaline soils of southeastern Montana was extracted by DTPA. Total lead in minesoils and native range of the Great Plains varies from 10 to 30 ppm (Munshower et al. 1978, Severson et al. 1978). Assuming a DTPA extraction of 10 percent, total minesoil lead levels 10 times present concentrations (10 to 30 ppm x 10 = 100 to 300 ppm) would yield DTPA lead levels within the range of present suspect levels set by the State of Montana (10 to 20 ppm). Yet these concentrations would have no effect on seed germination, plant growth, or animal performance.

Published lead suspect levels are unrealistic in terms of effects on vegetation, water pollution, and potential animal toxicity. There is no evidence to show that these levels actually inhibit plant growth or seed germination, nor is there evidence to show that water pollution or animal health is threatened in alkaline soils of the coal regions of the Great Plains. The extensive analyses presently performed on soils and overburden are, therefore, not of value and the resources devoted to these analyses are largely wasted. Automobile and smelter emissions of lead which accumulate on vegetation or in soils are much more important to the health of the range ecosystem than potential lead in overburden or soil materials.

Like lead, cadmium uptake by plants poses a threat to grazing animals. Because of its physiological action and storage in soft tissues of herbivores, smaller quantities of this element in plant tissues present a potential animal health hazard. Soil and plant cadmium levels are correspondingly much lower than lead levels in comparable segments of the food chain. Soil levels toxic to plants or animals are poorly defined, but some information about these concentrations may be inferred from the many studies reported in the literature.

Swaine (1969) presented only a meager list of soil cadmium references. Bowen (1966) quoted a total soil cadmium range of 0.01 to 0.7 ppm, but his data were primarily from Vinogradov (1959). Severson's studies (Severson et al. 1978) on the Northern Great Plains showed total soil and subsoil cadmium levels to range from 0.01 to 0.04 ppm. My studies have revealed more than 0.7 ppm. In southeastern Montana topsoils, DTPA extraction rarely revealed more than 0.1 ppm cadmium (Munshower et al. 1978), and Severson and his co-workers (1978) found extractable levels up to 0.3 ppm with an average of 0.1 ppm in surficial soils of the Great Plains. It is evident that Great Plains soil cadmium levels, as measured by strong acid or DTPA extraction, are less than 1 ppm.

Soil cadmium is more soluble and has a slower reaction time than lead (Jurinak and Santillan-Medrano 1974); therefore, elemental additions to soils in plant uptake research tend to remain in a plant-available form for longer periods than similar additions of lead. Scientists who have investigated the reaction of vegetation to cadmium have reported responses to soil levels as low as 2.5 ppm (Haghiri 1973, Miles and Parker 1979). Study soils were commonly allowed only a short period for added elemental cadmium to become fixed by soil complexes. The plant-available soil toxicant in these experiments was near or above the level of added cadmium.

Thus, reports of plant growth inhibition after addition of cadmium sufficient to elevate the soil level to 2.5 ppm are more reflective of DTPA extraction levels of 2.5 ppm than total concentrations of this level.

Despite the reaction time of this element, its solubility in alkaline soils is much reduced. Studies in the severely polluted Deer Lodge Valley of Montana indicated that air pollution-derived cadmium was retained in the upper soil profile for many years (Munshower 1972). Movement of this element deeper into the soil profile appeared to be restricted to the depth of soil acidification by sulfur dioxide pollution despite more than 50 years of relatively constant cadmium fallout. Mild acid-extractable cadmium concentrations of 1.8 ppm were recorded in pastures recently seeded to wheat grasses. These pastures showed abundant growth and reproduction of the seeded grasses.

It is likely that DTPA-extractable soil cadmium levels approximate weak acid-extractable cadmium concentrations. If 1.8 ppm weak acid extractable soil cadmium had no observable influence on seed germination and plant growth, 1 ppm DTPA-extractable cadmium is also unlikely to inhibit seed germination or plant growth.

Because of the solubility of cadmium in acid soils, plants may absorb relatively large amounts of this element (plant concentrations in the Deer Lodge Valley commonly exceeded soil levels). Increased plant uptake is restricted, however, by the high pH of most Great Plains soils. These highly buffered soils also restrict loss of this element by the limited leaching that results from the meager precipitation occurring in the region. Elevated cadmium levels in vegetation or groundwater of the Great Plains are not a threat when soils and overburden are alkaline. Thus, analyzing for overburden or topsoil cadmium levels is not a justifiable expenditure in soils with neutral or higher pH values.

Zinc

This metal was identified as a plant nutrient in the early years of this century. However, its essentiality was not widely accepted until the 1930s when several investigators reported correction of little-leaf or rosette-type bud growth with additions of the element. These two syndromes are now known to be characteristic of zinc deficiency (Chandler, et al. 1931, Parker 1934). Zinc toxicity to plants was also identified shortly thereafter (Gall and Barnette 1940).

Soil pH is extremely important to zinc solubility (Shuman 1980). In acid soils, extractable zinc may react 10 to 40 ppm, but in Great Plains soils normal DTPA-extractable zinc levels range from only 0.3 to 4.2 ppm (Munshower et al. 1978, Severson et al. 1978). These concentrations are well below plant inhibitory levels, plants extracted more zinc from the root zone than extractants indicated were available. Evidently plants selectively absorb zinc from soil complexes that extractants are unable to solvate (Hodgson 1963).

Plant inhibition by zinc usually occurs in acid soils or contaminated areas such as metal mine waste disposal sites (Rascio 1977). Toxic concentrations of this element in natural soils are uncommon, and plant inhibitory levels in naturally alkaline soils have not been recorded. Inducing zinc toxicosis in pine trees on coastal plain soils of Florida required addition of 200 to 300 ppm zinc to the root medium (Van Lear and Smith 1972). Another study in Nebraska utilizing zinc additions up to 700 ppm failed to produce toxicity symptoms in corn (Chesin 1967). It must be noted, however, that corn is zinc tolerant.

Plant zinc levels may become elevated if soil concentrations are abnormally high, but grazing animals rarely show any observable symptoms. Elemental concentrations 100 times greater than background usually produce no detectable toxicosis in animals (National Research Council 1979). Efforts devoted to analysis of this element in alkaline materials at mine sites in the Great Plains are wasted, since the probability of plant or animal poisoning by this element is extremely small.

Copper and Molybdenum

Both copper and molybdenum are recognized plant nutrients and reviews of their biological importance are available elsewhere (National Research Council 1977b, Allaway 1977). Copper is well known for its plant inhibitory properties (Reuther and Labanauskas 1965); it was one of the first elements to be used for weed control. High levels of soil molybdenum, on the other hand, have little or no effect on plant growth. But the adverse influence of this element on livestock production has led to the identification of vegetation and later of soils rich in molybdenum.

While deficiences of both elements in plant root media occur, of more immediate concern to the livestock industry are low soil copper concentrations and elevated soil molybdenum levels. Legumes grown in such an environment may reveal elevated molybdenum concentrations and produce a syndrome in grazing animals referred to as molybdenosis. This disease is an induced or conditioned copper deficiency created by an excess in the diet of the copper antagonist--molybdenum. Because of the well-defined interaction between these two metals in animal nutrition, they have been considered simultaneously here.

The ratio of these two elements in the animal diet is important. As mentioned above, high levels of molybdenum can produce a copper deficiency. Low levels of molybdenum and high copper in the diet can produce a simple copper toxicity, while low molybdenum and low copper concentrations can produce a true copper deficiency. Lesperance (1967) published a chart simplifying these relationships (Table 3). Ratios of 2:1 (copper:molybdenum) represent a critical point, but for a general guide, values of 5:1 or higher are desirable to meet ruminant nutritional needs (Miltmore and Mason 1971, Lesperance 1967).

TABLE 3. MOLYBDENUM AND COPPER CONCENTRATIONS IN FORAGES AND RESULTING LIVESTOCK DISEASES*

Forage Level		Disease State
Cu	Mo	
>50	--	Copper toxicity
5-15	1-5	Normal
5-8	5-50	Molybdenosis
<5	0.1-5.0	Copper deficiency

*From Lesperance 1967.

Follett and Lindsay (1970) reported that DTPA-extractable copper concentrations in 37 Colorado soils ranged from 0.2 to 3.2 ppm in "A" horizons and varied little with depth to 40 cm. Both Severson et al. (1978) and Munshower et al. (1978) reported similar soil copper ranges in the Northern Plains. A very thorough study of 313 soils in Montana by Haby and Sims (1979) showed copper concentrations to range from 0.3 to 3.0 ppm, with one sample at 10 ppm.

Naturally occurring excesses of extractable copper have not been reported in the soil literature (National Research Council 1977b). This is due to the sparse occurrence of the metal as well as reduced solubility at pH values above 6. In laboratory studies of copper excess, above-ground vegetation does not normally accumulate toxic copper concentrations because most copper uptake is bound in non-mobile forms in the plant roots (Jarvis 1978). The root bound fraction may reach 96 percent of total plant copper when uptake rates are high. Copper deficiency is much more common than copper excess and has been reported in soils of the Northern Great Plains (Deutscher et al. 1977, Munshower and Neuman 1978b).

Molybdenum concentrations in Great Plains soils have not been as thoroughly investigated as copper concentrations. Unpublished work by the author showed plant-available concentrations between 0.1 and 0.3 ppm (Tamm's extraction) in seven distinct grassland study sites in southeastern Montana. Soils at these sites were sampled at 10-cm increments from the surface to 40 cm. One "badland" site revealed soil molybdenum in excess of 0.7 ppm. Vegetation on this site was sparse, but plant chemical analyses did not indicate that molybdenum availability in the soil was enhanced. Analyses of minesoils at three sites in a molybdenum uptake study showed 0.2 to 0.6 ppm of extractable molybdenum (Neuman and Munshower 1981).

Elevated molybdenum concentrations in natural soils have been reported (Clawson 1974). This problem usually occurs in alkaline soils which have high water tables. In such soil, availability of copper is reduced, molybdenum is not removed by leaching, and molybdenum availability is enhanced by conversion to the anion. Cattle may develop molybdenosis if they consistently graze forest legumes grown in such an environment.

Legumes contribute to the severity of molybdenosis or conditioned copper deficiency on high molybdenum pastures. These plants accumulate more molybdenum and copper than grasses, but copper is absorbed less efficiently by cattle from green forage than it is from dry hay (Lesperance 1967). The incidence of molybdenosis is, therefore, increased on fresh pastures of mixed grasses and legumes. Sulfate has also been identified as a factor involved in this syndrome, although some confusion exists concerning the research. High sulfate in the root medium decreases molybdenum uptake by plants (Sims et al. 1979). High sulfate in animal diets also reduces intestinal absorption and increases excretion of both molybdenum and copper (Underwood 1976). The final effect of high sulfate on the ratio of these two elements in animal diets is not clear.

Because of the possibility of a nutritional imbalance developing in cattle grazing on minesoils, some type of testing program appears to be desirable. However, the complex relationships between plant and soil levels of copper and molybdenum cannot be deciphered in the minesoil prior to mining. Present agency policies that require soil and overburden analyses for copper and/or molybdenum do not prevent an imbalance from developing after minesoil revegetation. Therefore, plant analyses for these elements sometime after reclamation and prior to bond release are recommended. If minesoil vegetation is to be grazed as part of a management program, analysis should take place prior to grazing. Furthermore, copper and molybdenum analyses should be performed on each species of dominant vegetation on the site. The presence of molybdenum-accumulating plant species should be weighed in terms of their production on the site. If imbalances occur in the vegetation, trace element fertilization or other measures may be undertaken to correct the situation.

Selenium

There are no recorded incidences of selenium toxicity to plants in natural environments (National Research Council 1976). This element is thought to be an essential plant nutrient only for a few species (Broyer et al. 1972). Plant nutrient deficiencies have not, therefore, been reported for this element. Nevertheless, with respect to animal nutritional needs, both deficiencies and excesses of this element have been reported in vegetation (Franke 1934, Oldfield et al. 1963).

Minesoil selenium concentrations are important because of their potential influence on vegetation levels and the resultant effects on animal diets. The history of animal poisoning by plant selenium is very old even in this country. It was first noted in cavalry horses at Fort Randall in the Nebraska Territory in 1857 (National Academy of Sciences 1971). Animal deficiency symptoms, however, have been identified only recently (Schwarz and Foltz 1957). The relationship of selenium deficiency with "white muscle disease" in cattle and horses has been clearly established (Hartley and Grant 1961, Muth et al. 1958). The Northern Great Plains has the dubious distinction of exhibiting both deficiencies and excesses of this element.

Soils of the Great Plains that have developed from Cretaceous sedimentary rocks may contain as much as 100 ppm of selenium (National Academy of Sciences 1971). Fortunately, total soil concentrations do not indicate potential plant levels because of the variety of forms of selenium that may be present in soils. Of the various extraction techniques proposed for the analysis of plant available soil selenium, the water soluble method has been most widely mentioned (Kolm 1975). However, Lakin (1961) maintained that in alkaline, seleniferous soils of the semiarid West, neither total nor water-soluble selenium has any direct relationship to plant selenium levels.

In the soil this element may be present in several forms. In low pH soils, selenite and elemental selenium predominate (Ulbrey 1980). Alkaline, well-aerated soils usually contain selenium as calcium selenate, a highly soluble and presumably plant available form of the element (Williams and Byers 1936, Olson _et al_. 1942).

Selenium uptake from acid soils is reduced by the insolubility of this element in such soils. In alkaline soils with high selenate levels, the data are inconsistent. For example, Hurd-Karrer (1937) reported 350 ppm of selenium in wheat grown in sand cultures containing only 2 ppm of the element as selenate, while Olson _et al_. (1942) reported 35 ppm of selenium in _Agropyron smithii_ grown in soil with soluble, selenium concentrations of 17.6 and 19.0 ppm. Other factors apparently contribute to the regulation of plant uptake of this element; for example, the ability of soil sulfur to reduce plant uptake of selenium has been reported (Lakin 1961, Hurd-Karrer 1935). Allaway (1970) maintained that the selenium toxicity problem of the Great Plains would be much more serious if it were not for the high sulfur levels of most seleniferous soils in the region.

Rosenfeld and Beath (1964) classified vegetation into three groups with respect to selenium uptake. Various other authors have used a similar classification, but different titles for the groups (Kolm 1975, Beath _et al_. 1939). The following three groups incorporate concepts from several of these authors.

1. Primary Selenium Accumulators--These plants (also referred to as selenium indicators or selenium convertors) appear to grow on highly seleniferous soils and accumulate large concentrations of the element (up to several thousand ppm). They may require selenium for normal growth and development (Trelease and Beath 1949). Examples include species of the genera _Astragalus_ (especially _A. bisulcatus_) and _Stanleya_, among others. These plants may also absorb normally non-available selenium from the root zone and convert it to organic selenium which, upon the death and decomposition of the primary selenium accumulators, becomes available for absorption by other plant species (Beath 1937).

2. Secondary Selenium Absorbers--These species will accumulate a few hundred ppm of selenium if present on seleniferous soils. Genera include _Atriplex_, _Grindelia_, _Gutierrizia_ and others. Species in

groups 1 or 2 with high selenium contents are usually avoided by grazers if other forages are available.

3. Non-Concentrators--Most crops, grasses, and many weeds fall into this last group. They rarely contain more than 30 ppm of selenium.

Acute poisoning only occurs when animals eat fairly large quantities of selenium accumulator plants. Since animals normally avoid these species, this type of toxicity rarely occurs. Chronic poisoning, also called alkali disease, has been reported to result from the ingestion of small quantities of accumulator plants over several weeks or months (Rosenfeld and Beath 1964). Vegetation selenium levels that contribute to chronic toxicity are poorly defined, but Graham (1973) reported diet levels in excess of 5 ppm may produce such symptoms. Various other papers support a similar toxicity level (Whanger 1974, Buck and Ewan 1973).

Soil concentrations that contribute to toxic selenium concentrations in vegetation vary with the plant species, forms of selenium present, and other physical and chemical characteristics of soil. Parent material and the intensity of weathering and leaching are among the most important factors determining plant-available selenium on the Great Plains (National Research Council 1976). Because of the difficulty in defining soil toxicity levels, Kubota et al. (1967) and many other investigators have utilized plant selenium levels to define areas of soil deficiency or toxicity. This has proved more reliable than soil analyses for detecting deficiencies or excesses of the element.

The use of water soluble selenium extracts to identify potential excesses of selenium in minesoils or overburden is inadequate and expensive. Pre-mining identification of primary or secondary selenium accumulators on the area to be mined is a more accurate indicator of a selenium soil problem than soil analysis. In seleniferous areas not colonized by selenium-accumulating species (e.g., Campbell County, Wyoming), water extraction of the element is the only available method of identifying elemental excesses in surface soils. Unfortunately, this method is inadequate and may not reveal elevated soil selenium levels when the soil is seleniferous. In non-seleniferous areas of the Great Plains in which pre-mining vegetation studies do not identify a significant number of selenium indicator species, water extraction of soil selenium is redundant and should be discontinued.

Overburden samples will only yield elevated water soluble selenium levels if the element is present as the selenate. Other forms of this element, which may be converted by aeration, weathering, or plant action to water soluble selenate, will not be detected by the presently recommended procedure. Therefore, it may be better to identify the seleniferous black shales which are the parent materials of the seleniferous soils of the western plains (Lakin 1973) by other methods (i.e., visually, drill logs, etc.) and to segregate them on some basis other than chemical analysis of selenium. Burial of these potentially toxic materials below the root zone will better protect future plant communities than haphazard analysis of drill core samples by a technique of limited value.

Boron

Boron was one of several trace elements to be identified as plant nutrients during 1920 through 1940 (Sommer 1927). The history of boron toxicity dates back farther with reports of boron excess being published in Europe in the early part of this century (Bradford 1965). Plants show a variable response to this element. Eaton (1944) developed lists of boron sensitive, semitolerant and tolerant species. Unfortunately, most of the plants he studied were agricultural species, and few western range plants are found on his lists. Animals do not appear to be threatened by any realistic plant concentration of this element (Jenkins 1980).

Boron soil concentrations generally reflect the origin of soil parent materials (Bingham 1973). Sedimentary deposits usually contain higher boron concentrations than igneous rocks. Marine shales, in particular, reveal high boron levels. This element is adsorbed on soil particles as boric acid in acidic environments but is converted to the anion (borate) in alkaline soils and increasingly adsorbed as the soil pH approaches 9.0. Both adsorbed forms are in equilibrium with the soil solution. Because of the solubility of this element in either form, and the greater concentration found in sedimentary parent materials, problems with boron are more common in western alkaline soils despite increased adsorption. While elevated levels are associated with alkaline, semiarid environments, toxic concentrations do not usually occur in arable soils (Murphy and Walsh 1972). When phytotoxic boron concentrations are found in soils they are usually associated with irrigation (Kubota and Allaway 1972).

Boron in the soil solution may be leached from the profile (Rhoades et al. 1970). In the arid West, where the soil pH has encouraged the weathering of boron in parent materials to borates, precipitation is not sufficient to remove these anions. Thus, elevated boron (several ppm) may be found in soils or groundwaters of this region.

A number of soil factors influence plant uptake of boron as well as its form in the soil. High calcium concentrations retard boron uptake (Muhr 1940). Coarse-textured or sandy soils appear to adsorb less boron than fine-textured clay or clay-loam soils; thus, fine-textured soils are inherently less subject to boron toxicity (Wear and Patterson 1962). Soils generally adsorb greater quantities of boron at higher pH values (Gupta 1979). These variables probably account for the absence of boron toxicity in most arable western range soils.

Hot water soluble boron is the accepted analytical tool for determining levels of plant-available forms of this element in the soil (Cox and Kamprath 1972). This method is widely recommended for analysis of low boron levels. For plant toxicity studies, analyzing water-soluble boron in saturation extracts is the preferred method (Richards 1954, Bingham 1973).

Boron soil levels (water-soluble) above 1 ppm are considered toxic to sensitive crops; Branson (1976) reported that extracts of 5 ppm approach the limits of semitolerant vegetation, and levels of 10 ppm approach the limits of tolerant species. Soil concentrations of these magnitudes generally produce plant boron levels of 20 to 100 ppm for vegetation not showing deficiency or toxicity symptoms. In a recent study by the author (unpublished), ponderosa pine needles showng boron toxicity symptoms revealed levels of 370 to 1250 ppm. The vegetation injury ranged from slight to severe. Background levels of boron in the same species indicated 20 to 25 ppm. Apparently healthy specimens of pine near a source of boron pollution showed concentrations from 100 to 300 ppm. The literature also supports a concentration of 100 to 300 ppm as the range at which boron injury to vegetation becomes visible.

The method for determining plant available soil boron is reliable but pronounced species-dependent sensitivity or tolerance render the analyses of little value. Agency-defined "suspect" levels also have little meaning, since native range species deficiencies or toxicities are not known. For example, in Eaton's (1944) studies alfalfa showed maximum growth with root medium boron levels of 5 or 10 ppm, and injury symptoms developed at 15 ppm. Sweetclover was growing well in the highest soil concentration used in the study (25 ppm), but injury developed at concentrations as low as 10 ppm. Kentucky bluegrass produced maximum biomass and injury symptoms at 1 ppm boron. If the boron suspect level is set low enough to protect Kentucky bluegrass, alfalfa growth will be restricted. If the suspect level is set high enough to maximize alfalfa production, Kentucky bluegrass will be inhibited. In my unpublished study mentioned previously, healthy plants of *Agropyron spicatum*, *A. smithii*, *Juniperus communis* and other common range species were found under pine trees that were severely injured or dead. The question on mined lands to be addressed is, therefore: What plants are to be protected and what plants are to be encouraged? This decision will influence boron suspect levels.

A recent paper by Severson and Gough (1982) reported a very significant, linear relationship between water-soluble boron and electrical conductivity in minesoils of 11 active coal mines on the Great Plains. These results suggest that the common analysis of electrical conductivity of soils could be used as a first screening for boron problem soils. A program similar to that proposed for selenium would offer better protection to vegetation on minesoils than the present procedures. Where boron may have a known history of plant toxicity or on potential minesoils that exhibit high electrical conductivities (>5-10 mmohs/cm), the present sampling and analysis procedure should be strengthened to include both water-soluble and total boron. In the vast majority of mine sites on the Great Plains, analyses of irrigation water, postmine inspection for visible injury to vegetation, and soil analyses if dictated by the inspection would offer more economical and better probability of detecting adverse boron impacts.

Arsenic

This element, although toxic to plants and animals, is found on only one Western State agency list of minerals for analysis in soils or overburden. Arsenic (usually sodium arsenite) has a history of herbicide use dating back to 1890, and organic arsenic herbicides are still in use today (National Research Council 1977a). This element is also known for its insecticidal properties and was widely used for this purpose prior to the introduction of organic insecticides in the 1940s.

Arsenic is not abundant, but it can be found in small quantities in most soils (Greaves 1934). It is often associated with sulfide ores and may reach concentrations of several hundred ppm in soils overlying these deposits (National Research Council 1977a). Despite its phytotoxic properties, arsenic has not been reported to occur in concentrations high enough to injure plants in natural soils. Episodes of arsenic-induced plant injury have always been due to air pollution or prolonged use of arsenic insecticides (Vincent 1944).

Total soil arsenic concentrations have little relevance to plant effects (Olson _et al_. 1940). Mild acid extractable arsenic levels more accurately reflect plant-available soil concentrations. Mild acid-extractable soil arsenic levels around 5 ppm are considered toxic to sensitive plant species (National Research Council 1977a), but some selenium soils of South Dakota have higher arsenic levels (up to 14 ppm) with no apparent effect on vegetation (Olson _et al_. 1940). Like boron and selenium, arsenic availability in soils is controlled by a number of factors that produce an often bewildering picture of plant availability (e.g., texture, other available elements, pH, etc.).

In the Helena Valley Study (EPA 1972), surface soils at 1 and 2 miles from the East Helena smelter contained 123 and 40 ppm total arsenic, respectively. Most of these soils supported grasses or weeds, and some were cultivated for grain production. Growth of the seeded grains or grasses was not measured but appeared to be equivalent to that outside the severely impacted areas. Plant-available arsenic must have been very low in these polluted soils to support any but the most resistant vegetation.

Vegetation collected by Gough and Severson (1981) from the Great Plains yielded arsenic concentrations of less than 1 ppm in most samples; however, a few wheat grass and alfalfa samples indicated between 1 and 3 ppm. These higher arsenic levels were not restricted to mine sites but were found in vegetation from the minesoils and non-mined lands. Concentrations of this magnitude (1-3 ppm) in occasional vegetation are not high enough to produce undesirable effects in grazing animals.

The present policy of not analyzing for arsenic in soils and overburden of potential mine sites is an adequate reflection of our present state of knowledge. Naturally toxic overburden is highly improbable in alkaline materials and if such material occurs, no positive method exists for identifying it.

Mercury

The history of mercury toxicity to mammals is very old. The ancient Greeks were well aware of the potential for animal poisoning from metallic mercury (d'Itri 1972). More recently in Japan (between 1953 and 1960), mercury poisoning afflicted 111 inhabitants of the area around Minamata Bay. In this episode methylmercury was the responsible agent (Lofroth 1970).

Prior to the 1960s small releases of inorganic mercury were thought to be diluted in soils and water. Most scientists assumed that the metal was not available for uptake by terrestrial plants or algae in concentrations high enough to produce a toxicity problem. Unfortunately, an aquatic bacterium was subsequently found to convert inorganic mercury to more soluble and more toxic organic forms that are accumulated by plants and animals (Jensen and Jernelov 1969). Despite their greater potential danger to animals, organic mercury compounds rapidly replaced inorganic mercury fungicides and pesticides. As a consequence of the introduction of these organic compounds, significant increases in mercury concentrations occurred at successive stages of certain food chains. The resultant ecological disasters have lead to wide restrictions on the use of all mercury compounds today.

The application of organic mercury compounds as fungal control agents in apple orchards and on seed grains testifies to the low toxicity of this element to terrestrial plants (Stone 1964, Smart 1963). Shacklette (1965) reported tree and shrub roots in contact with cinnabar (mercury ore) in an Alaskan mineral deposit. The vegetation revealed very high mercury levels (0.5-3.4 ppm) but showed no toxicity symptoms.

Vegetation usually shows relatively low mercury levels in unpolluted areas (0.02-0.03 ppm). Similar concentrations were found in vegetation growing on strip mined lands in the Great Plains (Gough and Severson 1981). In contrast, mercury concentrations in vegetation of polluted urban areas may range up to 1.0 ppm (Shacklette 1970, Huckabee 1973). In cereal grains grown from mercury-dressed seed, straw or seed, mercury levels may be slightly elevated, but there is much debate on this point (Vir and Bajaj 1963, Lofroth 1970). Nevertheless, the use of mercury coatings on such seed has been directly related to drastic decreases of wild bird populations in Sweden and has now been prohibited in that country (Lofroth 1970).

Shacklette et al. (1971) reported on the mercury contained in 912 surface soil samples collected in this country. In the western United States levels ranged from less than 0.01 to 4.6 ppm. The mean value for the western half of the country was 0.083 ppm, and for the eastern half, 0.147 ppm. Urban areas in general revealed higher mercury levels in soils and vegetation than rural areas (Gowen et al. 1973, Yeaple 1972). Metallic mercury in the soil may be volatilized or converted to mercuric sulfide or other mercury compounds. The volatilized mercury is, of course, lost to the atmosphere until it is washed out by rain but mercury compounds may be converted to other forms by geochemical and biological actions (Battelle Columbus Laboratories 1977).

Soil mercury has a low toxicity to plants. Shacklette's (1965) report of vegetation growing in 40 ppm mercury in A2 and B horizons over cinnabar deposits definitely indicates a low soil phytotoxicity for this element. The concern of regulatory agencies is not, therefore, with soil concentrations toxic to plant seed germination or vegetative growth, but to potential food chain accumulations. Such accumulations presumably could be produced in overburden brought to the soil surface by mining.

Overburden must be covered with topsoil at all coal mines. When geologic materials are brought close to the soil surface, they will remain buried by this covering of topsoil. Because of the very low concentrations of mercury in all soil materials analyzed around the world, the probability of significantly elevated mercury concentrations in overburden materials is very low. If elevated mercury levels were present (over 1 ppm is a conservative estimate of a high level) the mercury would require conversion to an organic form to pose a threat via food chain accumulation. This would require bacterial methylation of very stable mercury sulfides to organic mercury in an environment in which such activity has not been heretofore observed. The threat to wildlife or cattle posed by such a phenomenon is much less than the threat posed by legitimate uses of mercury-based fungicides on golf courses, in urban areas, and as seed dressings. The very expensive analysis of overburden for mercury, therefore, is not justified at this time.

SUMMARY

The analytical programs designed by various regulatory agencies to detect potential or actual elemental excesses in mine-site soils and overburden are ill conceived. The analytical procedures, toxicity levels, sampling intensities, soil reactions, etc. necessary to accomplish the goal of these programs are in many cases unrealistic and impractical. Published soil elemental suspect levels are not even based upon the presently available literature. In some cases the guidelines are too restrictive, in others the indicated suspect concentration has never been recorded, and in some the concentration may or may not have any effect, depending on other factors.

A possible alternative is this three-part program:

1. Strengthen the requirements for interpreting relationships among soil factors that have shown strong influences on reclamation success on the Great Plains (i.e., pH, electrical conductivity, sodium absorption ratio or estimated sodium percentage, texture, etc.).

2. Place more emphasis on the plant species growing on lands prior to mining.

3. Define toxicity in terms of the vegetation produced after rehabilitation of the mine site and retain the right to require corrective action if necessary prior to bond release.

In effect, this report suggests and supports an almost complete deletion of soil and overburden elemental analyses from pre-mining inventory requirements. However, certain extremely important soil parameters were not evaluated in this paper. These include such things as pH, conductivity, sodium adsorption ratios (or estimated sodium percentage), and texture, all of which directly influence trace element availability. For example, if pH analyses indicate acid conditions in what will become the minesoil, this entire presentation loses all validity. The arguments presented here assume the normal, alkaline, semiarid environment of the Great Plains.

Some of the coal fields of Wyoming reveal overburden materials that oxidize upon exposure to the atmosphere and produce acid environments. In these areas extreme care must be taken to bury the acid-generating overburden materials to prevent the contamination of surface soils. If acidification occurs, the loss of surface vegetation follows, and soil erosion is imminent. But even in these acid soils the present analytical programs may not identify potentially toxic materials.

This paper does not intend to say that elemental toxicities cannot possibly occur, but rather that the present programs are inadequate for predicting with any degree of certainty: (1) a plant growth inhibiting elemental level occurring, or (2) an animal toxicity level arising from elevated plant elemental concentrations. Some of the supposed elemental toxicities probably cannot occur in this region (e.g., zinc, copper, iron, etc.) but proof of this would require extensive elemental research into soil chemical forms and changes, solubility constants, oxidation-reduction reactions, and other related and poorly understood chemical phenomena. Such a large amount of research is beyond the scope of any individual scientist.

If a program such as the one presented in this paper was adopted and a toxicity problem subsequently developed on minesoils, what alternatives would remain for the regulatory agency? Implementation of a drastically curtailed analytical program in mine site overburden and soils would require that the mine operator be cognizant of his responsbility if a toxicity problem developed after revegetation was complete. Remedial action must be required regardless of the expense. This, of course, could include any type of appropriate activity determined by the regulatory authority, such as fertilization or leaching, application of a new surface soil layer, or deeper burial of a toxic overburden material.

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THE SOIL RESOURCE: ITS IMPORTANCE IN THE WEST AND ITS ROLE IN COAL DEVELOPMENT AND RECLAMATION

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INTRODUCTION

Soil resources are of critical importance in sustaining human and most other forms of animal life on earth. The standard of living enjoyed by mankind in the developed portions of the world is to a significant extent attributable to a solid agriculture based on the presence of extensive and productive soil resources. Soils are composed of both biological and physical components which serve as the transition from the physical elements of bedrock or geologic materials and the atmosphere to the biotic community. Soil characteristics and productivity are influenced greatly by these parameters.

Mankind's perception of the soil resource ranges widely. To many of today's urbanites, soil is primarily a component of the vast agricultural and recreational lands lying many miles beyond the realm of influence directly affecting their lives. Unfortunately, many American agriculturalists and others from highly industrialized societies regard it as a media into which technological inputs are made to produce an agricultural crop. In contrast, the typical East African has little understanding of one of the resources that his life is almost totally dependent upon. Soil characteristics and productivity, along with precipitation, often dictate day-to-day survival of the young and elderly in many of the lesser developed countries. In general, mankind neither understands nor cares about this resource, yet two-thirds of more of the world's population is either under- or malnourished--grim testimony to the lack of recognition of the capacities and limitations of the resource that produces most of the foodstuffs utilized by man.

What then is this crucially important resource? Why is it so unique? Exactly how important is it? Does it influence our lives? What are the importances of soil resources to reclamation of surface mines and mitigation of environmental impacts? First, just what are soils?

Concepts or Definitions of the Soil Resource

A typical dictionary definition of soil would include that it is the upper layer of the earth that may be dug or plowed and/or in which plants grow; soil is the superficial, unconsolidated and usually weathered part of the mantle of the planet; the loose surface material of the earth in which plants grow, usually consisting of disintegrated rock with an admixture of organic matter and soluble salts. Lastly, soil may be defined as cultivated or tilled ground.

Soils are better described, at least more completely, by authors from the fields of natural resources and soil science. Donahue et al. (1971) describe soil as a "three-dimensional, dynamic, natural body occurring on the surface of the earth, which is medium for plant growth and whose characteristics have resulted from the forces of climate and living organisms acting upon parent material, as modified by relief, over a period of time." The Canadian Soil

Committee (1978) describes soils as "naturally occurring, unconsolidated mineral or organic material at the earth's surface that is capable of supporting plant growth. Its properties usually vary with depth and are determined by climatic factors and organisms, as conditioned by relief and hence water regime, acting on geologic materials and producing genetic horizons that differ from the parent material."

Buckman and Brady (1972) in their classic introductory soil text define the resource:

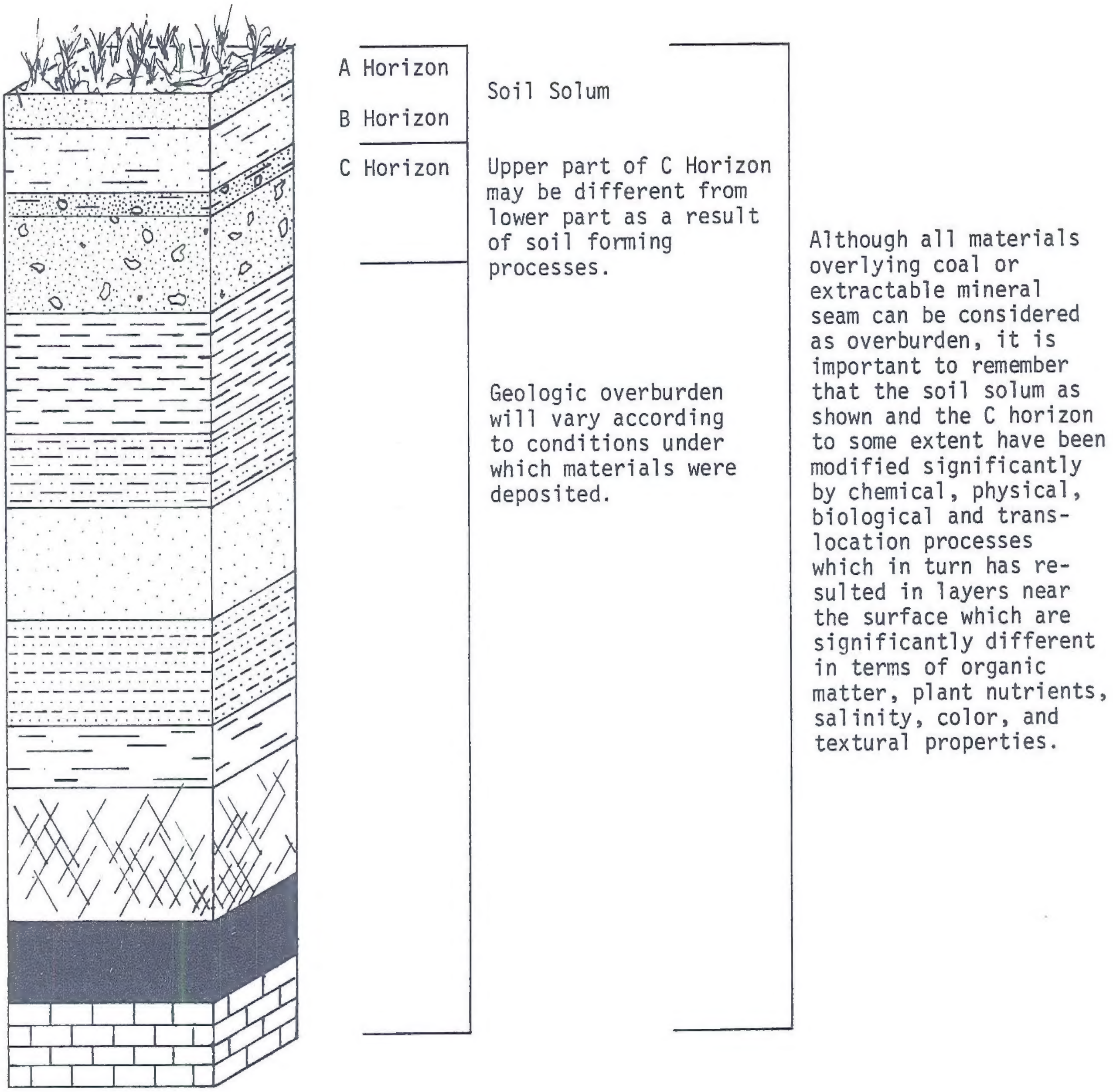
> . . .as a natural body, synthesized in profile form from a variable mixture of broken and weathered minerals and decaying organic matter, which covers the earth in a thin layer and which supplies, when containing the proper amounts of air and water, mechanical support and, in part, sustenance for plants.

Soils are frequently described as three-dimensional, natural bodies occupying large portions of the landscape. Figure 1 from Barrett (1980) illustrates the vertical dimension of the soil profile. They are capable of supporting the growth of higher plants and have been biogeochemically altered by soil-forming processes. The latter include climate, relief, parent material, time and the biotic or organic fraction. The biotic community is crucial in the development of the soil resource. Plant succession frequently parallels soil development. Soil organic matter, one of the principal components of most soils, is a product of the activities of living organisms. The living components of the soil system control many of the potential uses which can be made of the resource and its associated productive capacity.

The Soil Survey Staff (1975) describes soil as:

> . . . the collection of natural bodies on the earth's surface, in place modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors. Its upper limit is air or shallow water. At its margins it grades to deep water or to barren areas of rock on ice. . . Soil includes the horizons near the surface that differ from the underlying rock material as a result of interaction, through time, of climate, living organisms, parent materials and relief.

Soil science has been divided, albeit arbitrarily, into two basic approaches to the study of the resource--pedology and edaphology. The pedological approach concentrates on the origin, characteristics and description of individual soils and their classification. Edaphology views a soil as a media for the growth of higher plant life. Its primary concerns are the characteristics of the soil and how they influence plant growth. Both approaches are enhanced greatly by the information gathered by the other. As



Upper part of C Horizon may be different from lower part as a result of soil forming processes.

Geologic overburden will vary according to conditions under which materials were deposited.

Although all materials overlying coal or extractable mineral seam can be considered as overburden, it is important to remember that the soil solum as shown and the C horizon to some extent have been modified significantly by chemical, physical, biological and translocation processes which in turn has resulted in layers near the surface which are significantly different in terms of organic matter, plant nutrients, salinity, color, and textural properties.

Figure 1. Soil horizonation and relationship to overburden and coal resources (Barrett 1980).

an example, an older, dark-colored, well-developed soil having developed from sodic parent materials on the till plains of North Dakota (Natriboroll) potentially may not be well suited to the use of the deep-rooted crops--depending upon the position of the natric horizon (zone of accumulation of clay and significant amounts of sodium). In this case, the classification, and, to some extent, genesis of the profile, which is reflected in the term "Natriboroll," describes characteristics of importance to the edaphologist, for they control the potential for the production of agricultural crops, native grasslands and the suitability of the soil for surface mine reclamation.

ROLE OF SOILS IN THE NATURAL SYSTEM

Soil resources form the bridge between the bedrock or geologic materials in the landscape and the cultivated crops, pasture land and native plant communities found in the ecosystem. Soils are often, but not always, related to the bedrock underlying them and many of the soil characteristics or properties are related to the properties of the parent material or rock.

The essential nutrients for the growth of plants, excluding the gas carbon dioxide and, to a more limited extent, nitrogen for legumes and other nitrogen-fixing plant species, are obtained from the soil. Two of the important macronutrients, nitrogen and, to a more limited extent, phosphorus, are obtained primarily from the organic matter in the soils of arid lands. Fertilizers are used to enhance fertility and crop production and are primarily confined to nitrogen, phosphorus and potassium. Many other elements are essential for plant growth but are needed in much lesser quantities or concentrations than those described above. These include calcium, magnesium, iron, manganese, and copper, etc., and are primarily derived from the mineral portion of the soil.

Elements are taken up as ions from the soil solution rather than required for plant growth in the solid phase. Understanding and appreciating the solubilities of the various soil minerals and salts are critically important in evaluating materials for use in reclamation. For example, if soil materials are selected which have a very low pH, such as 4.0, it can be predicted that the vast majority of the plants growing on such a soil will suffer from a phosphorus deficiency. The deficiency develops because of the relative insolubility of the phosphate anion at those reactions--and the deficiency is brought on by complexing of the anion with iron cations which are particularly soluble at that pH range. Extremely low pH values such as these are only rarely encountered but they always are associated with relatively high concentrations of sulfur. Examples would include soils developing in shales or other sedimentary rocks which have high levels of sulfur or secondary minerals such as jarosite series, impounded soils such as those found in the Mekong delta of Vietnam, and minesoils developing in overburden materials having high concentrations of iron pyrite.

In the Western United States, the importance of the soil resource to the agricultural industry and its role in such ecosystems can perhaps best be illustrated by the widespread use of the range site concepts of Dyksterhuis (1949, 1952, 1958a, 1958b). The arid lands of the West are dominated by native vegetation which through the years has proven best adapted to the factors which influence plant growth in the natural system. Such factors include soils, climate, history and type of utilization or disturbance, etc. Plant ecologists and range managers have discovered that one of the better ways of classifying rangeland is to describe the general kinds of soils found there and the plant communities they support. Through the study of relict areas and other pristine sites, man has been able to develop aggregations of soils which, at times, would have similar potential to produce or support plant communities.

Along with the similarity in floristics, such aggregations or range sites have been shown to have similar potentials for production of biomass under similar ecological conditions--ecologic condition and amounts of precipitation. This classificational system has been the mainstay of the range management programs and livestock allocation in the Western United States but the underpinning of the system is the knowledge of the soil and its capacities to support the growth of native plant species.

The production of crops such as wheat, barley, etc., or the more intensively managed hay crops are often controlled by the distribution and characteristics of the soil resource and its interaction with other environmental factors. Several characteristics of the resource are important in determining the productivity of the land and they are often influenced by external environmental conditions as well as the crop being grown. In Big Horn Country, Montana, the amount of soil organic matter, depth of the soil solum, redistribution of surface runoff water, infiltration and water-holding capacity, salinity and alkalinity levels and soil texture would be important factors influencing winter wheat yields. In Delaware County, Indiana, the amount of soil erosion, organic matter, drainage, depth of the solum, structural development, texture and permeability/infiltration would be of particular importance in the production of corn. Some overlap in factors obviously exists but there are significant differences both in the type of inputs and their relative importance in the production of the crop. Supporting data for the conclusion that various kinds of soils have differing productive potential for a given crop is found in Table 1. As an example, from the soil-mapping units identified in Big Horn County, Montana, Soil Survey Table 1, the range in winter wheat production is from 14 bushels for the Gilt Edge silty clay loam, 0 to 2 percent slopes to 42 bushels for the Farnuf loam, 0 to 2 percent slopes. Precipitation and management inputs are held constant in this case. The slope component of the soil-mapping unit is another critical factor in crop production or potential use of the land. Table 2 gives evidence of the importance of this factor to the agricultural industry. It takes on at least equal

TABLE 1. PREDICTED AVERAGE YIELDS PER ACRE OF PRINCIPAL CROPS IN BIG HORN CO., MONTANA

	Winter wheat dryland (Bu)	Alfalfa hay dryland (tons)	Alfalfa hay irrigated (tons)	Pasture dryland (AUM)	Range Site
Absarokee silty clay loam, gently undulating	35	1.5	--	1.2	Clayey
Amherst loam, rolling	22	--	--	1.0	Silty
Arnegard silt loam, 2 to 4 percent slopes	32	1.3	5.0	1.3	Silty
Bew silty clay loam, 0 to [illegible] percent slopes	23	1.0	5.0	0.8	Clayey
Colby association, rolling	15	1.0	--	0.6	Silty
Farnuf loam, 0 to 2 percent slopes	42	1.6	5.0	1.2	Silty
Fort Collins loam, 0 to 2 percent slopes	30	1.1	5.5	0.9	Silty
Gilt Edge silty clay loam, 0 to 2 percent slopes	14	0.5	3.0	0.9	Dense Clay
Haverson loam, 0 to 2 percent slopes	30	0.9	5.5	0.9	Silty
Heldt silty clay loam, 0 to 2 percent slopes	23	1.0	5.0	0.9	Clayey
Lennep loam, 2 to 4 percent slopes	35	1.1	--	1.3	Clayey
Marias clay, 2 to 4 percent slopes	36	1.2	4.0	0.9	Clayey
Renohill silty clay loam, undulating	22	0.9	--	0.9	Clayey
Shonkin clay loam	36	1.1	--	1.3	Overflow
Thurlow silty clay loam, 0 to 1 percent slopes	29	0.9	5.5	0.9	Clayey
Vananda clay, 0 to 1 percent slopes	--	--	--	0.3	Dense Clay

AUM = Animal Unit Months. An animal unit month expresses the carrying capacity of pasture. It is the number of animal units or 1000 pounds of line weight that can be grazed on an area of pasture for 30 days.

Source: Meshnick, J.C. et al. 1977. Soil Survey of Big Horn County Area, Montana. U.S. Dept. of Agriculture, Soil Conservation Service and U.S. Dept. of Interior, Bureau of Indian Affairs in cooperation with the Montana Agricultural Experiment Station.

TABLE 2. CROP PRODUCTION AND LAND CAPABILITY POTENTIAL RESPONSE TO SLOPE GRADIENTS

	Crop Yields	Land capability unit
A. Marshall Co., Mississippi		
Lexington silt loam, 5 to 8 percent slopes, severely eroded	450 lbs cotton 6.1 AUM Bahiagrass legume	IIe_1
Lexington silt loam, 8 to 12 percent slopes, severely eroded	Unsuited for cotton 5.0 AUM Bahiagrass-legume	IVe_1
B. Rio Grande Co., Colorado		
Luhon loam, 1 to 3 percent slopes	3.0 tons alfalfa 250 cwt. potatoes 70 bushel barley	$IIIe_1$
Luhon loam, 3 to 6 percent slopes	2.5 tons alfalfa unsuited for potatoes 60 bushel barley	IVe_2
C. Delaware Co., Indiana		
Blount silt loam, 0 to 2 percent slopes	105 bushel corn	IIw_2
Blount silt loam, 2 to 4 percent slopes	100 bushel corn	IIe_{12}
Blount silt loam, 2 to 4 percent slopes, eroded	85 bushel corn	IIe_{12}

if not greater importance in surface mine reclamation. The production from minesoils in the postmining landscape are influenced in a similar fashion and additionally the slope gradient will have a strong impact on the stability of the landscape. The importance of the character of these surface materials (minesoil surface horizons) and associated slopes are not considered adequately in the development of current reclamation plans.

On many ranches in the Northern Great Plains portion of the West, the capacity of a ranch for hay production is the limiting factor determining the numbers of livestock that can be carried. A balance must be struck in these areas between winter forage represented by hay crops and the carrying capacity of the native summer ranges. Simply the cost of purchasing hay from sources off of the ranch is too expensive over the long run; subsequently, the rancher must limit the number of stock carried to meet the availability of hay produced internally. Referring again to Table 1 for Big Horn County, Montana, please note some of the potentials for production of alfalfa and dryland pasture. Figure 2 illustrates the size and importance of the hay-producing lands.

One of the more important methods of increasing production of crops of hay in the West has been irrigation. The availability of water, its cost and quality, and the kinds of soils available for such use on a farm or ranch will to a large part determine whether irrigation can be successfully developed or carried out over the long term. Soils having poor drainage, high clay contents, moderate or high levels of salinity or alkalinity are simply poor bets to try and develop the expensive types of irrigation systems generally being installed today. Yields, as reflected in Table 1, are a significant factor in evaluating whether an irrigation system can be economically developed or not. In the Third World countries, the information about the soil resource is of critical importance in deciding such efforts at increasing food production should take place. The high capital commitment required for the development of irrigation, which is a practice frequently being relied upon, leaves no margin for error in these areas. If the project fails, the results are simple--people will starve or critically needed funds will be diverted from medical or educational programs pivotal to the development and maintenance of the well-being of the populus.

The relationship between the soil resource and wildlife is an often missed concept (Fig. 3). Allen (1962) in Our Wildlife Legacy entitles Chapter 2 "They Grow In Soil," which perhaps best states the case. As an example, poor soils generally produce less quantities of forage which is of poorer quality than the more fertile soils. The Soil Conservation Service, which is responsible for soil survey in the United States, includes interpretative data for wildlife with each of the soil series. Refer to Appendix A and the interpretative data for the soil series included.

The concept of an ecosystem, a biotic community and its nonliving environment interacting in a systematic manner, is or should be a fundamental entity of land management. The close relationship that exists between the soil resource and plant community and other biotic portions of the habitat of wildlife

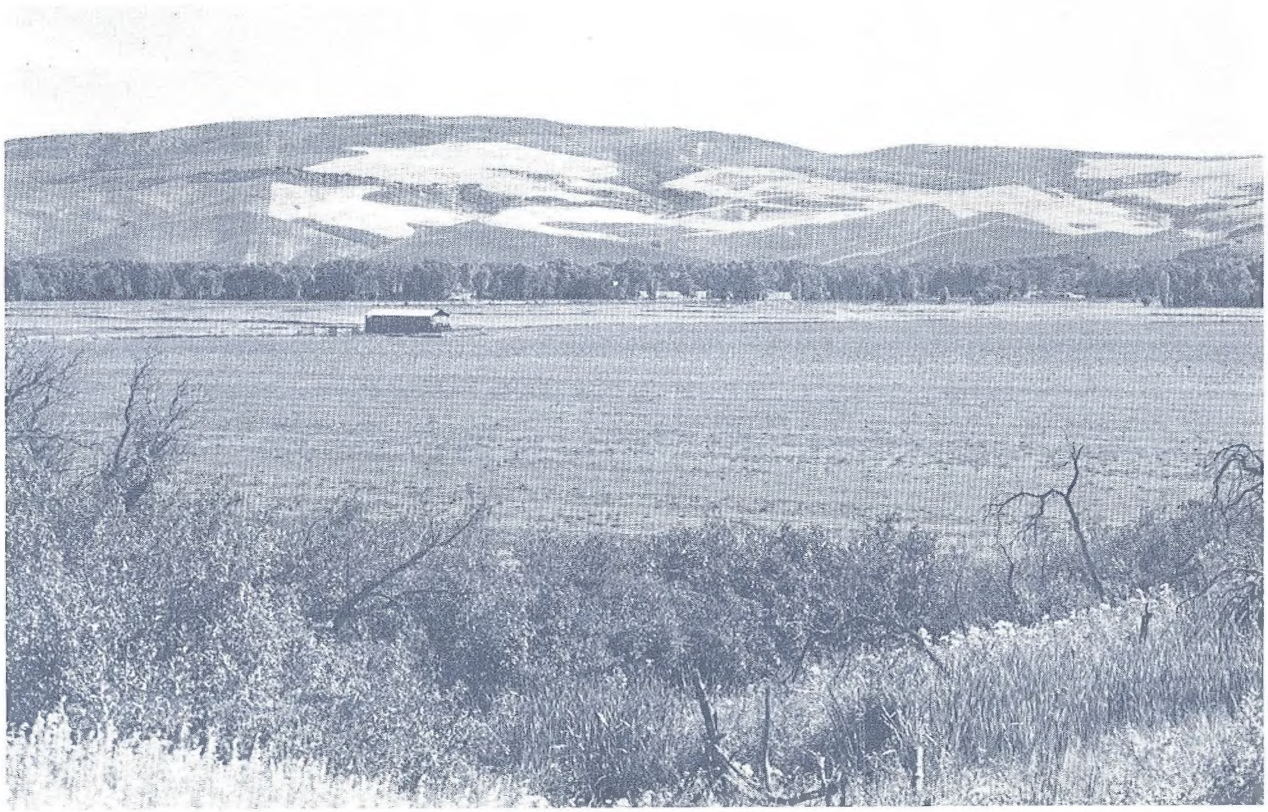


Figure 2. Irrigated valleys and flood plains are critically important to the agricultural industry in the arid West. Forage produced from these areas is necessary to carry livestock through the winter months (near Craig, Colorado; photo--S. Fisher).

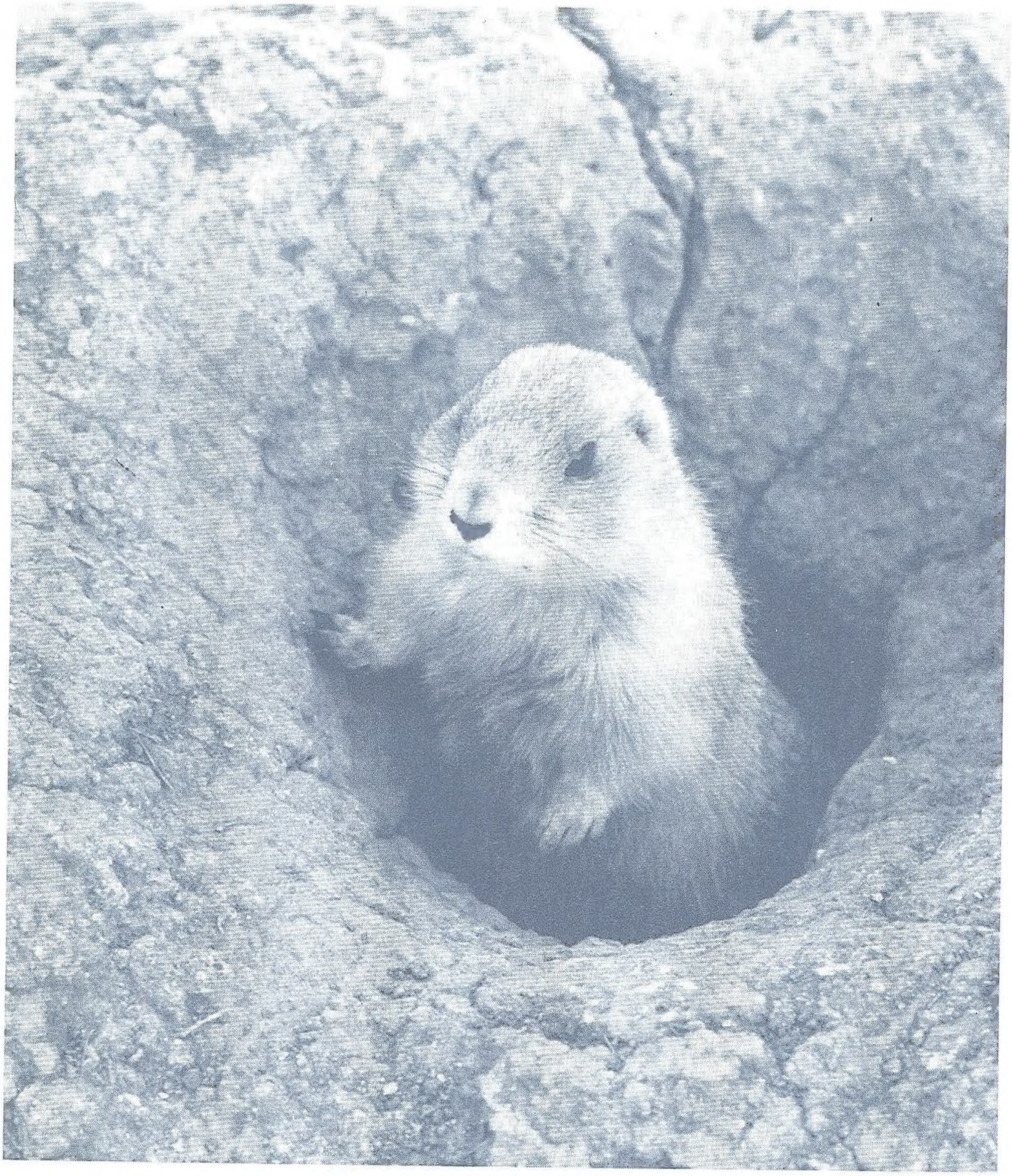


Figure 3. The distribution of animals such as the Blacktail Prairie Dog (Cynomys ludovicianus) is associated with the distribution of soil materials which have sufficient structural stability, depth, etc., to provide suitable habitat (photo--S. Fisher).

demonstrates that management must approach problems on the basis of the total system rather than any single segment of the problem. Allen (1962) states:

> "By now most people are acquainted with the well-worn saw that poor land makes poor people--both in numbers and quality. In time they will learn of such soil; also that its deer and turkey, its rabbits and quail, its coons and muskrats will be few, and frequently poor."

The Serengeti Plains of northern Tanzania support one of the world's largest concentrations of mixed plains wildlife. Reconnaissance level soil and related ecosystem studies by Grzimek and Grzimek (1960), Pearsall (1957), Talbot (1956), Fisher (1977), and Anderson and Talbot (1965) suggest a strong correlation between the soils and closely related recent geologic influences, the vegetation and the distribution and abundance of wild ungulates. The plains have a basement of Precambrian rocks which are overlain by lacustrine tuffs interbedded in the southern and western portions with quartz sands and gravels. The eastern portion of the plains have been altered dramatically by very recent aeolian deposits of dark-colored ashes (lithochromic materials) from Oldoinyo Lengai eruptions in 1940-1941, 1921 and 1917. Anderson and Talbot (1965) recognized seven soil vegetation associations in the Serengeti. They are as follows:

1. Juvenile soil on volcanic ash;
   Dactyloctenium/_Sporobolus_ dune country
2. Calcimorphic soils with hard-pans;
   Sporobolus/_Kyllinga_ short grasslands
3. Calcimorphic soils with soft-pans,
   Cynodon/_Sporobolus_ intermediate grasslands
4. Vertisols of lithomorphic origin;
   Pennisetum/_Andropogon_ long grasslands
5. Brown calcareous soils;
   Themeda/_Pennisetum_ long grasslands
6. Vertisols of lithomorphic origin in south;
   Pennisetum/_Cynodon_ medium grasslands
7. Associations on kopjes

The distribution of the vegetation in the Serengeti National Park is closely correlated with that of the soil resource. The characteristics of the soil, total amount and distribution of effective precipitation and vegetative response have been found to be the more important factors influencing distribution of wild ungulates. Important soil characteristics include susceptibility to wind erosion, texture, salinity-alkalinity soil depth, depth of soil solum and related illuviation and development of soluble salts. Additionally there is evidence that the more recent soils dominating the eastern side of the plains have significant manganese deficiencies which influence the composition and cover of plant species/communities. Thomson's gazelle (Gazella thomsonii), zebra (Equus burchelli) and wildebeest (Connochaetes taurinus) are the most numerous species in the Serengeti Plains (see Fig. 4). Their distribution during the wet periods is primarily confined to the plains specifically being governed by the availability of fresh water and forage.

Anderson and Herlocker (1973) reported on the soil-vegetation type, wildlife distribution and utilization within Ngorongoro Crater southeast of the Serengeti Plains in Tanzania (Tanganyika). The most numerous species, including wildebeest, zebra, Thomson's gazelle and Grant's gazelle (Gazella granti), spend most of their time on the caldera floor grasslands. The analysis found that soil factors are of the greatest importance in determining the distribution and characteristics of the vegetation types and their utilization by wild animals. Twelve soil/vegetation associations were recognized within the caldera which ranged from the swamp complex to the Vertisols of the depressions to the lithosolic creep complex. Table 3 illustrates the seasonal use by big game species on the various vegetation types.

Management and research efforts currently being undertaken on the Kruger National Park in South Africa strongly emphasize the relationship between the base resource components of geology, hydrology, soils and vegetation and the wildlife populations inhabiting the reserve (Joubert, Director of Research at Kruger National Park, personal commun. 1983). Relatively detailed inventories of the geology-hydrology-soils components provide much of the baseline resource inventory information for land-use planning in the park. A detailed vegetation inventory is being supplemented on an annual basis with permanent vegetation transect data which, when evaluated with existing soils information, makes evaluating plant community trend possible. Extensive use of aircraft are made in wildlife transects to determine the number of animals by species and their distribution in the reserve. All base resource and wildlife population data are digitized allowing correlations between existing plant communities. Their trends, soils and the distribution of large animal species are made to facilitate management decisions in the park. The result of much of the work is determining the carrying capacities for individual wildlife species and evaluating harvesting needs, if necessary. Programs of this type are one of the better examples of a holistic approach to the intelligent management and utilization of natural resources.

The characteristics of the terrestrial portion of the biosphere and its component ecosystem are in no small part dependent upon the soil resource. The woody draws of the Northern Great Plains which are of such great concern

TABLE 3. GAME UTILIZATION OF VEGETATION TYPES THROUGHOUT THE YEAR IN NGORONGORO CRATER, TANZANIA.

Vegetation types	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
(1) *Cyperus/Aeschynomene* swamp complex						Hippopotamus, zebra, wildebeest, rhinoceros, reedbuck, elephant ←	—	—	—	→		
(2) *Chloris/Cynodon* grassland					←	Mainly larger ungulates, zebra, wildebeest —	—	—	—	→		
(3) *Acacia xanthophloea/ Achyranthes* woodland	←	Mainly rhinoceros, elephant, hippopotamus, zebra, wildebeest, waterbuck —	—	—	—	—	—	—	—	—	—	→
(4) *Sporobolus/Odyssea* sparse very short grassland						Mainly Thomson's gazelle ←	—	—	→			
(5) *Sporobolus/Cynodon* very short grassland	Mainly wildebeest, zebra, Thomson's gazelle ←	—	—	—	—	→					←	—
(6) *Digitaria/Cynodon* short grassland	Mainly wildebeest, zebra, Thomson's gazelle, kongoni ←	—	—	—	—	—	→				←	—
(7) *Cynodon/Digitaria* medium height grassland	←→				Mainly wildebeest, zebra, eland, Thomson's gazelle ←	—	—	—	→			←
(8) *Pennisetum/Cynodon/ Andropogon* medium height grassland					Zebra, wildebeest and gazelle ←	—	—	—	—	→		
(9) *Cynodon/Andropogon/ Digitaria* medium height grassland					Zebra, kongoni, eland, wildebeest, gazelle ←	—	—	—	—	→		
(10) *Andropogon/Digitaria/ Themeda* medium height grassland						Gazelle, zebra, wildebeest, kongoni, buffalo ←	—	—	—	→		
(11) *Themeda/Setaria* tall grassland with *Lippia*						Mainly Grant's gazelle, zebra, eland, buffalo, elephant, kongoni ←	—	—	—	→		
(12) Woodland/forest/bushland complex	Mainly zebra, buffalo, eland, Grant's gazelle, klipspringer, kongoni, elephant ←	—	—	—	—	→					←	—

Source: Anderson and Herlocker 1973.

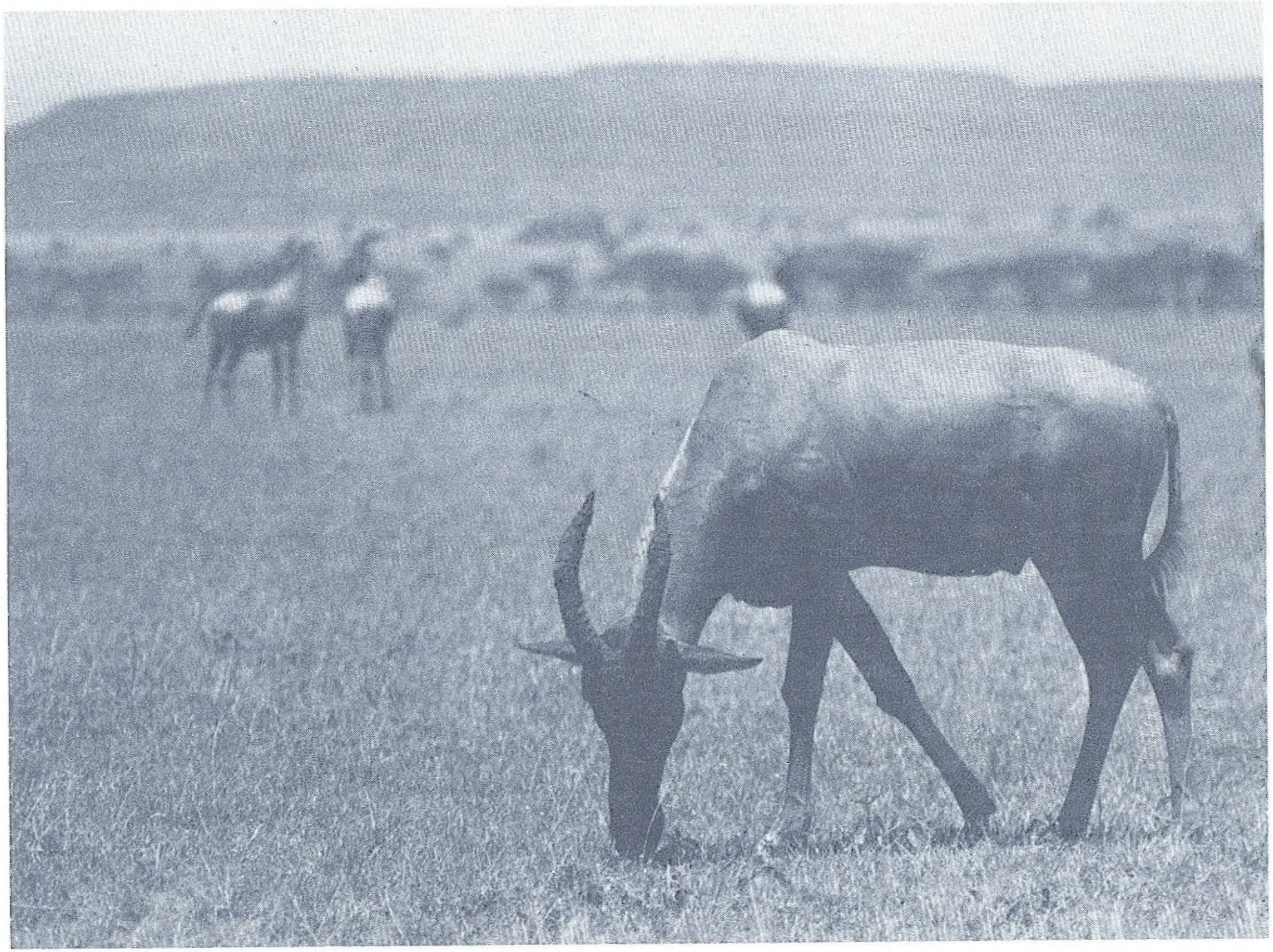


Figure 4. Topi in the Serengeti National Park near Seronera, Tanzania, which is an immense grassland area thought to be edaphically controlled. Many of the soils are very recent in origin, having received significant deposition from wind-blown sediments from active volcanoes to the east such as Oldonyo Lengai (photo--S. Fisher).

today in coal reclamation efforts have resulted from a combination of unique soils and hydrologic characteristics partially resulting from their position in the landscape. Such plant communities are critical habitat for wildlife and of very considerable importance to the livestock industry in this region. Soils from the woody draws are rarely identified in low and moderate intensity soil surveys but their properties are a major reason for the presence and characteristics of the plant communities found in these draws. The correlation between the soil resource, the plant communities that it supports and the fauna which it supports either as wildlife or feral stock cannot be overemphasized in any study of land management or utilization.

Crawford (1950) reported box trap studies in Missouri on size and densities of cottontail rabbits (Sylvilagus floridanus) was much greater on the more productive soils (see Fig. 5). Rabbits taken from northeastern Missouri weighed one third more and had large leg bones with breaking strengths 37 percent greater and 12 percent larger than rabbits from the poor soils. Crawford (1950) concluded that the best individuals came from the most productive land. The Missouri work was extended from cottontail rabbits to raccoons (Procyon lotor) and muskrats (Ondatra zibethica) with similar results.

As described earlier in this section, soils are the primary link between bedrock systems and the biotic community. The soils role in the biogeochemical cycles which drive and control much of life through the cycling of nutrients is a pivotal one. In most cases, the nutrients are not directly absorbed by plants from soils then utilized by herbivores and passed on to the carnivore level of the food pyramid and then lost to the system. There are major losses in energy transfer at all levels in the generic food chain just described--losses in efficiency occur both between producers and consumers and through lack of utilization by the consumer organisms. Interestingly, in the natural state, the major elements supporting such growth are not lost to the ecosystem because they are recycled back into the system. There are very few open-ended nutrient pools.

Several good examples of the biogeochemical cycle activity are available, but the two were selected for discussion here--selenium (Se) and the sodium interaction with the Greasewood (Sarcobatus vermiculatus) plant both being particularily important to the West and reclamation activities. The role of selenium has been intensively studied at the University of Wyoming and other academic institutions since the 1930s (Beath 1934, 1935, 1947). The interest was triggered by large, acute losses of sheep when herded on to portions of the range in the Shirley Basin area of Wyoming. Selenium is substituted for sulfur in several of the sulfur-containing amino acids--methionine, cysteine and cystine. It may be particularly important in altering protein structure through its involvement in the disulfide bridges. Selenium, as is the case with most of the microelements, is required for both plant and animal growth at very low concentrations and yet is toxic to such organisms at higher levels (Rosenfeld 1964).

Figure 5. Wildlife diversity and productivity are directly related to the soil resource. Extensive live trapping efforts in Missouri have shown some soils to be much more productive in terms of cottontail rabbit populations than others. The close association between cottontails in the arid West and greasewood plant communities has been documented (photo--Wyoming Game and Fish Department, Cheyenne, Wyoming).

Specifically, there are ranges in concentrations which are suitable for the growth of plants; these ranges are defined by both the species (or ecotype) of plants growing on the soil and by the specific element in consideration (Beath 1959). Further complicating the situation is the interaction between elements/compounds as is the case with vitamin E and selenium or copper and molybdenum. Both the deficiencies and toxic levels of selenium are of importance to Western agriculture. White muscle disease (Hogue 1962) produced by selenium deficiencies is found in cattle in certain geographic areas such as the Bitterroot Valley of Montana, while the toxic conditions or levels of selenium are found in plant naturally occurring materials from the Como Bluffs and Shirley Basin areas of Wyoming, Bearpaw shale dominated in lands of south-central Weston County area of Wyoming and central Montana near Choteau which is dominated by shale bedrock or outwash from such materials.

The base levels of selenium in the bedrock and/or soils system and the subsequent uptake by plants are not well understood even with the long-term studies that have been undertaken (Allaway 1967, Olson 1967). In most cases, the soils upon which plants are growing having toxic levels of selenium are closely related to the bedrock--residual soils developing insitu from bedrock containing relatively higher concentrations of selenium. The Orthents and Fluvents, where such materials have been locally transported, dominate these kinds of soils. Unfortunately, the concentrations required for the development of toxicities in some plants are so low that they are near or at the sensitivity levels of available laboratory equipment. In extreme situations selenium concentrations have reached 5 ppm to 10 ppm in soils but in many cases toxicities have been reported on soils having one to two ppm. The second confounding factor is that the low concentrations of selenium in such soils are accumulated by certain species--particularly those belonging to the genera Astragalus, Oxtytropis and Stanleya. Such plant species frequently will contain in excess of a 1,000-ppm selenium in their tissues although growing on soils containing one or two ppm selenium (Hamilton and Beath 1963a, 1963b, 1964).

The primary importance of a basic understanding of the biogeochemical principles associated with selenium is to gain an appreciation for the holistic nature of ecosystems. These cycles have real importances to the economic well being of the agricultural industry through the mortality or loss in thriftiness of economically important classes of animals. Reclamation efforts on Western lands have to develop minesoils which will supply microelements at concentrations which are in accordance with the requirements of plant species to be used in the postmine plant community or crop. Additionally, the soils must not have the capacity to support the accumulator species which in turn would affect future use of the rangelands by man, his livestock or wildlife. The integrity of the plant community and soil system must be preserved in the postmine environment.

Greasewood (Sarcobatus vermiculatus) is the principal phraetophyte of the shadscale vegetation zone of the Great Basin. The species frequents terraces and flood plains (Billings 1951) which are generally moderately fine or fine-textured having moderately high levels of soluble salts and at times exchangeable sodium. Greasewood plant leafy tissue contains very high levels of sodium in their plant tissues which are obviously extracted from the soil system. Rickard (1965) reported sodium content of leaves increased from 45 mg/g in late April to 118 mg/g in early November. Being deciduous, these fleshy leaves fall to the surface of the soil and are incorporated into the A horizon, accomplished by decomposition of the plant materials by microorganisms while mixing with the soil occurs through freezing and thawing and development of dessication and/or shrink/swell cracks in the surface soil. The shrub thereby concentrates the presence of sodium in the surface layers of the soil. As a result, the soil environment encompassed by the canopy of the plant and zone of redistribution of leaves becomes heavily laden with sodium ions and soluble salts on some sites. Cheatgrass growing within the canopy has higher sodium concentrations than those in adjacent areas.

The sodium ion serves to effectively disperse the soil surface and to increase the osmotic pressures in the soil solution. The greasewood plant concentrates these in surface soil producing an environment that potentially reduces competition within the zone immediate to the plant. The plant alters the chemical and physical characteristics of the soil upon which it is growing.

In summary, the previous scenario describes the relationship between the parent rock bedrock which, in this case, must have some accumulatable concentrations of sodium. The soil retaining the sodium from the parent rock makes possible plant absorption of the sodium cations, the plant concentrates them in leafy material and the redeposition on the soil surface results in alteration of the basic soil characteristics.

SOIL CHEMICAL AND PHYSICAL CHARACTERISTICS AND THEIR IMPORTANCES IN RECLAMATION

When coupled with the biological component, the chemical and physical characteristics of soils frequently determine a soil's potential use and production capabilities and are the dominant basis of many of man's land use and management planning efforts. Agricultural science has learned to modify only a few of these characteristics and the work has concentrated largely on efforts to increase production from arable soils. Such technological changes or additions have been done largely without regard to secondary impacts on surrounding resources or long-term changes in the soils themselves.

The physical characteristics which frequently are of primary importance in describing and evaluating soils include texture, structure, color, temperature and density. The importance of these factors is illustrated in the current soil classification system (Soil Survey Staff 1975) where texture is a determinant at a family level, color (when correlated with organic matter) at the order level, and temperature at both the subgroup and family levels.

Soil physical properties having particular importance in determining reclaimability of a soil or site can be divided into two groups. First, the characteristics of the premine soil and resultant minesoil, which can be estimated in the field, include texture, infiltration, percolation, permeability and color, and can also be evaluated in the field. Secondly, those parameters which must be analyzed in the laboratory or for which supporting laboratory data should be acquired--hydraulic conductivity for which disturbed samples are primarily used, bulk density and mechanical analyses to support or verify field evaluations.

In agronomic terms, soil texture is described as the relative distribution of differing classes of soil particles as determined by mechanical analysis. Soil separates are the particle size categories or ranges which occur in soils. Particle size ranges are defined in the USDA Soil Survey Manual (Soil Survey Staff 1951). See Table 1. Each soil separate exhibits certain characteristics which influence soil behavior. Two of the primary importances of soil texture are chemical reactivity and soil moisture retention capacities. These factors are closely correlated in general with soil particle size and their respective surface areas. Chemical reactivity of the mineral fraction of soils is essentially confined to the finer portion of the silt fraction and to the clays. Corresponding soil surface areas by soil separates are given in Table 4 (Millar et al. 1966). Once the relative composition of soil separates has been determined, usually through mechanical analyses, the soil texture is calculated by using the textural triangle. The importance of soil texture to plant growth identified by Daubenmire (1942) includes: 1) relative resistance to root penetration, 2) infiltration of water, 3) rate of water movement, 4) water-holding capacity, and 5) fertility. Soil texture importance in reclamation is related to water-holding capacity, tilth, consistence, infiltration and percolation, permeability, soil temperature and cation exchange capacities. The extremes, clays and sands, including some intergrades such as loamy sands and silty clays, are to be avoided in selecting materials for reclamation. See Guidelines in Appendix B. Man has very limited ability to alter the texture of soils under natural conditions, but, in developing reclamation

TABLE 4. SOIL SEPARATES AND SEPARATE SURFACE AREAS

U.S. Dept. of Agriculture*		International Scheme**		
Name of Separate	Diameter (range; mm)	Fraction	Diameter (range; mm)	Surface Area in 1 Gram sq cm**
Very coarse sand	2.0 - 1.0			11
Coarse sand	1.0 - 0.5	I	2.0 - 0.2	23
Medium sand	0.5 - 0.25			45
Fine sand	0.25 - 0.10	II	0.20 - 0.02	91
Very fine sand	0.10 - 0.05			227
Silt	0.05 - 0.002	III	0.02 - 0.002	454
Clay	<0.002	IV	<0.002	8,000,000

* Soil Survey Staff. 1951. Soil Survey Manual.

**Millar, C.E. et al. 1966.

programs, within some constraints, it is possible to alter, by selection of materials, the texture of the resulting minesoils.

In much of the Western United States, water deficiencies are one of the primary causes for crop and/or reclamation failures. Total precipitation is not the single limiting factor, because certain soil properties also influence the supply of water for plant growth. In addition, redistribution of precipitation directly affects the amount of effective moisture available in any given place in the landscape. One property significantly influencing the water-supplying capacity of soil is texture. In general terms, it can be said that the more sand a soil contains, the more droughty it becomes. Generally, a soil dominated by the sand fraction has a very low water holding capacity, resulting in a very low water supplying capacity for plant growth. As the percentage of the clay fraction increases, water relations become more favorable for plant growth. The relationship is maintained until the clay fraction dominates the soil matrix (Fig. 6). At this point, much of the soil water is bound so tightly by the very small clay particles that it is unavailable for plant growth. In arid and semiarid environments, a clay textured soil may result in a droughty condition while less clayey soils may have sufficient moisture for plant growth.

Rarely are soils composed of individual or primary particles. Soil development and the attenuate biological activity within the soil result in aggregation of the primary soil particles into compound particles or soil peds. The ped is a naturally occurring soil aggregate. Soil structure is described in the Soil Taxonomy (Soil Survey Staff 1975) as "the aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from adjoining aggregates by surfaces of weakness." Soil structure is one of the primary characteristics which have been utilized in establishing the Vertisol order of soils. Figure 7 illustrates the cracking characteristics of these soils. The development and maintenance of strong water stable structural peds is of considerable importance in the long-term maintenance of cultivated agriculture. It should be one of the primary considerations in the long-term development and planning for reclamation efforts on minesoils. The importance of soil structure includes the movement of water into the soil (infiltration) and through the soil (percolation) and movement of air into and through the soil medium. The structure and permeability of the soil has a significant impact on soil microorganisms and root growth, the resistance that roots encounter growing into a soil medium and the nutrient status of the soil.

Soil structure can be developed or destroyed by man's land use and management practices. Cultivation or other manipulation of soils under high moisture status, overgrazing of rangelands or continuous monocultural cropping without returning crop residue to the soil system will generally destroy soil structure. The use of green manure crops, cultivation at appropriate soil moisture levels, application of animal or human waste products and selection-rotation of crops selecting deep-rooted species will all tend to enhance soil structural development. Under native range, the management of the resource to produce good or excellent range condition, limiting trampling during periods of high moisture and production of vigorous perennial grass and legume species would enhance development of and/or maintain soil structure. In surface mine

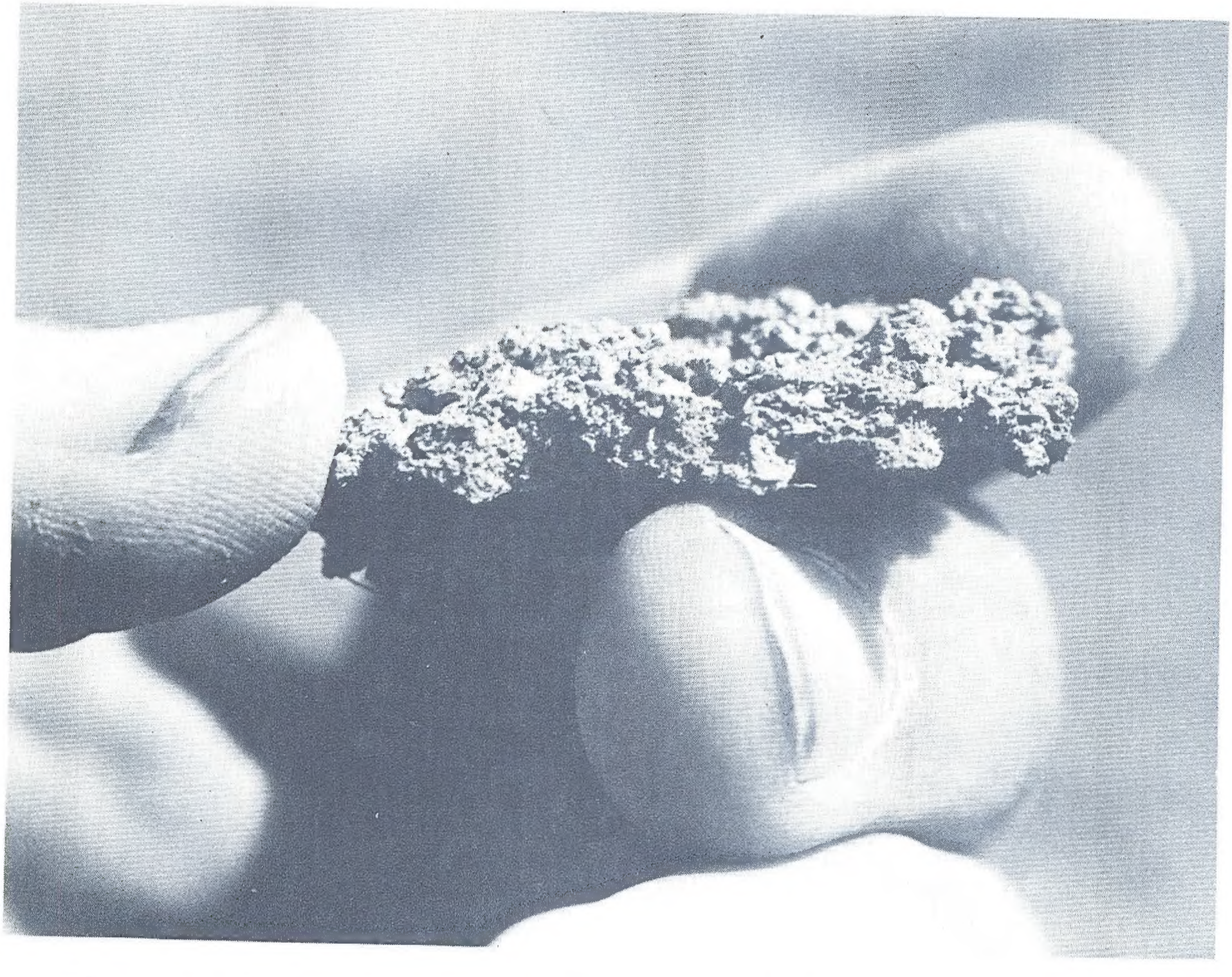


Figure 6. Vesicular soil structure which dominates the surface structure in several of the soils in the Northern Great Plains developing with elevated sodium concentrations in the parent material (Sheridan County, Wyoming; photo--S. Fisher).

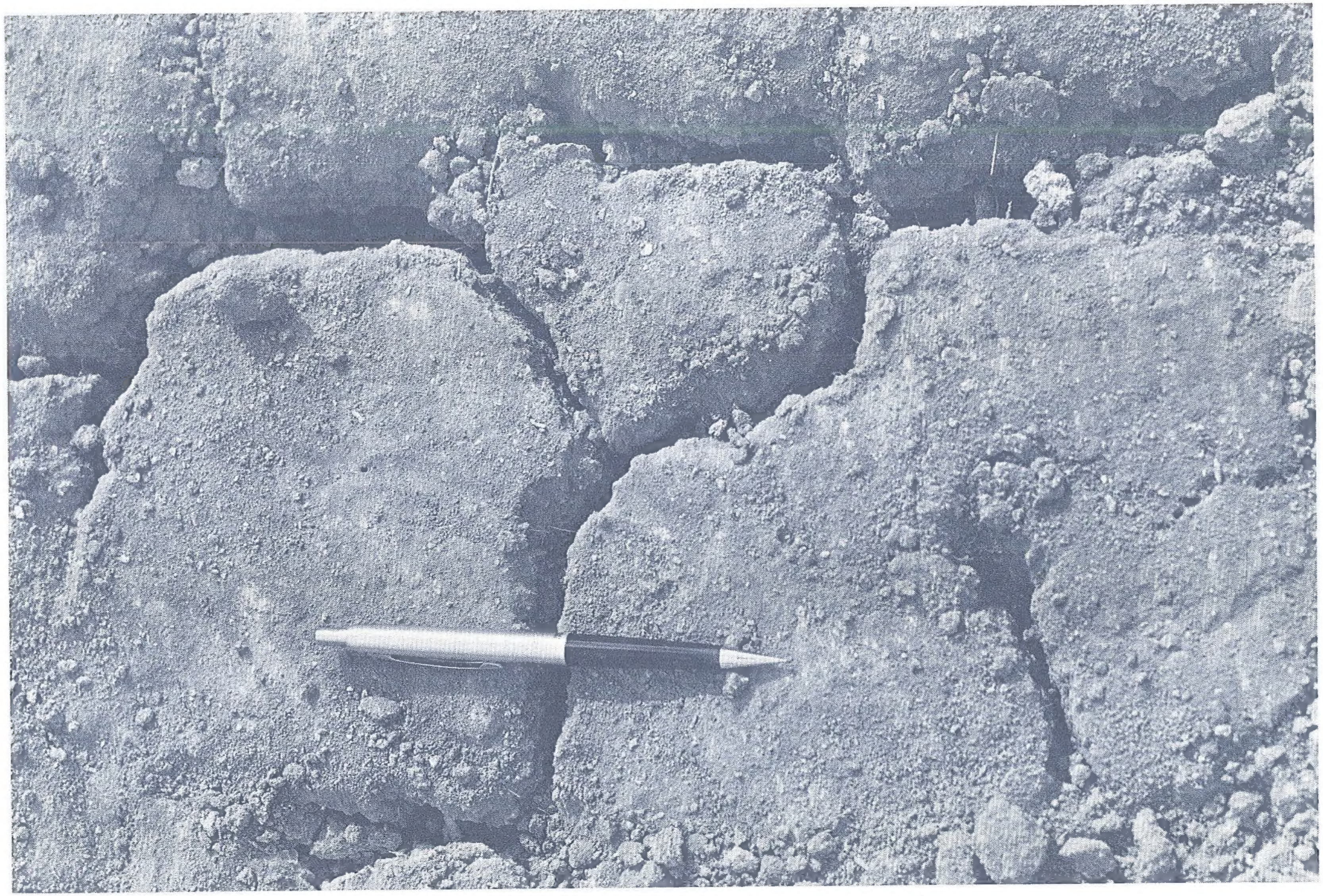


Figure 7. Soil structure controls most of the potential uses and limitations of the Vertisols throughout their distribution (near Green River, Utah; photo--S. Fisher 1981).

reclamation, the lack of strong soil structural development early in the formation of the minesoil at least partially results in the one- or two- year postmining reduction in infiltration and corresponding increase in surface runoff. The development of the compacted zone 18" to 48" below the minesoil surface which frequently takes place in reclamation of areas to cropland production results partially from the long-term deep penetration of roots and structural ped/fracture plane development (Ralston 1982). The frequently encountered mixture of soil materials horizons, parent materials and overburden strata make regeneration of structure a slow and difficult task to accomplish--particularly in arid environments.

Soil structure and slope also can have a strong, adverse effect on soil and plant water relationships. Generally speaking, the better defined a soil structure or the "stronger" a soil's structure, the easier water will enter the soil. The validity of this statement is to some extent dependent upon the type of clays (e.g., montmorillonite vs. kaolinite) dominating the clay fraction because, upon wetting, some clays expand, reducing the ability for water to enter the soil.

Soil organic matter, being dark colored or black, is often a key determinant of soil color; in fact, with some practice, an estimate of soil organic matter content can be made by evaluating soil color. Soil color is of only limited direct importance to soil-plant relationships, this occurring in terms of the absorption of incoming radiation and the effect on thermal balance. The darker soil surface colors are often indirectly related to high levels of soil organic matter which translates into higher inherent fertility levels and available water-holding capacities. Certain geological strata of the Fort Union and Wasatch formations in Montana, Wyoming, and North Dakota have sufficient amounts of carbonaceous materials to appear very dark grayish brown or black; yet they contain a very low amount of organic matter. Similar strata exist in other formations of sedimentary origin.

Such occurrences are widespread; Fisher (1977) reported such conditions near Mt. Meru in Tanzania in soils forming in recently deposited volcanic ash. Soils with low organic matter contents yet dark in color are termed lithochromic. The color of the parent material or rock is primarily responsible for the soil color in this case, but its influence extends far beyond these relatively isolated cases. The strong reddish hues dominant in the Redbed formation of northeastern Wyoming are passed on to the soils derived from such materials. Soil color is one of the prime characteristics defining the Mollisol and other orders in the Soil Taxonomy (Soil Survey Staff 1975). The colors of a soil sample are evaluated by comparison with the Munsell color chart and reported in terms defined therein.

Soil color is of significance in the development of reclamation plans and postmine soils. The potential for placement of dark-colored soil or overburden lithochromic materials in the minesoil is of real concern. These dark materials will absorb greater amounts of sunlight, have higher surface temperatures and greater losses of soil moisture than well-constructed minesoils. Such materials should be avoided through detailed soil inventory, careful soil salvage efforts and selected substitution of overburden materials. The steepness and length of the slope upon which a soil rests plays an important part in determining the soil-water relations and resulting plant growth.

In most situations, the steeper the slope, the more runoff produced or the faster water will move from it, thereby reducing the amount of water entering the system. Such factors modify the direct infiltration rate impact on the soil moisture relationships of a soil.

The bulk density of a soil, along with the amount of rock fragments and effective rooting depth, are factors which directly affect soil-water relationships and plant growth. Increased density of the soil horizon frequently results in the loss of porosity and permeability/percolation. These losses reduce the amount of water and air stored in a given volume of soil, thereby limiting the amount available for plant growth. High volumes of rock fragments, as well as shallow rooting depths, reduce the amount of soil material (<2 mm) available to store water and supply nutrients for plant growth. Problems of this sort are of real importance in selecting materials for minesoil construction. Where sufficient quantities of suitable material are available, materials high in coarse fragments should be generally avoided within the plant root zone--best defined as the light foot zone overlying spoil material.

The physical properties associated with a given soil are extremely important in determining its moisture-supplying capacity and plant growth potential. The precipitation, or better defined, the effective precipitation at a given site is the overriding factor in this discussion, but soil properties as described above are modifiers to the system.

Just as physical properties are important in determining a soil's potential for plant growth, so are the associated chemical properties. Many states involved in the regulation of surface mining and reclamation have published standards or guidelines on which to evaluate the chemical and physical properties of a soil for suitability as plant growth media. The guidelines (see Appendix B) that have been established in Montana and Wyoming for this purpose represent the "state of the art" and show ranges of chemical properties or characteristics which are acceptable from an environmental as well as a plant growth point of view.

In the past, much emphasis has been put on additions of chemical fertilizers or amendments in attempts to mimic the premine or "natural" system. However, work by Anderson (1979), Anderson et al. (1979), and Anderson et al. (1981) have demonstrated the importance of the organic fraction of soil materials in supplying nutrients to the natural system. Salvaging of topsoil material high in organic matter, as well as additions or organic residues (i.e., straw, manure, etc.), will aid in establishing an "organic pool" of nitrogen, phosphorus and sulfur. These nutrients are applied to a soil system through the decomposition of the organic materials by microbial action. Creation of the nutrient pool is important in reducing the amounts of chemical fertilizers needed as well as aiding in maintainence of the site fertility and stability.

Soil organic matter is generally reflected in the color of the soil and frequently concentrated in the surface horizons. Soil organic matter is the product of plant material which has been deposited on the soil surface and subsequently altered by microorganisms and incorporated into the soil surface horizon(s). Organic matter is intimately related to the development of soil structure and water-stable aggregates influencing water relationships of the soil system. Good tilth of a soil is frequently correlated with higher organic matter contents. Salvaging operations in surface mining must select soil materials having higher organic matter contents--preferrably exceeding two percent. Soils identified as being pachic or cumulic are of great importance in topsoil salvage operations because of the great depth of the organic matter-enrichened surface horizon(s). Soil organic matter contains much of the nitrogen and phosphorus in regional soils. Organic matter content in mineral soils of the Northern Great Plains ranges from less than one percent to more than ten percent. The lighter colored Aridisols will generally range up to one percent with the Mollisols having one to five percent organic matter. Laboratory analyses for organic matter are relatively simple.

Cation exchange capacity (CEC) is the quantity of ions held in an exchangeable form. The clays are layered latticelike particles which carry negative charges. Associated cations which neutralize these charges are found in the soil solution surrounding the clay particle. Different types of clays have vastly different cation exchange capacities; for example, kaolinite has a CEC of 2 to 15 meq while montmorillonite ranges from 60 to more than 100 meq/100 gm. Soil organic matter contributes significantly to the cation exchange capacity of the soil having 200 to 400 meq/100 gm of material. The CEC values for soils are an excelllent indication of their potential productivity. Analyses for CEC are of great importance in characterizing natural soils and in determining suitabilities of materials for reclamation.

Fertility-related tests are primarily for nitrogen, phosphorus and potassium which are the macronutrients required by most plants. Potassium levels are generally adequate in regional soils, but nitrogen and phosphorus are frequently deficient. Both elements are closely related to soil organic matter in native and naturally occurring soils and are part of the reason for the emphasis on salvaging topsoil in reclamation planning. Nitrogen and phosphorus are applied as commercial fertilizer, but long-term fertilization of native grasslands has not proven cost effective in most areas. Applying higher levels of nitrogen fertilizer results in depression of natural nitrogen-fixing processes in the soil. In Western soils, particularly those containing higher levels of calcium, phosphorus additions are rapidly bound in forms which are insoluble and therefore unavailable to plants. Addition of nitrogen- and phosphorus-containing fertilizers in revegetation operations should be based on soil fertility tests and the species used for revegetation.

pH or soil reaction is a parameter of great importance in determining the availability of many nutrients. The very low reactions of pH 5.5 and below are found in soils which are intensely weathered or contain oxidizable sulfur compounds such as pyrite or marcasite. When soil reactions drop to pH 4.5 or below, the presence of the oxidized sulfur product is involved. Naturally occurring soils containing relatively high levels of sulfur such as the Dilts

Series (see description and interpretative information in Appendix A) are found in the region and have very acidic reactions (pH <4.5). The intensely weathered, very acidic soils are not generally found in the Western coal-producing regions. When reactions exceed a pH of 8.5, they are produced by relatively high levels of sodium in the soil solution. The dispersive effect of the sodium ion is critically important and several of the nutrients required for plant growth are less available at reactions above 8.5. Optimum pH ranges for most uses would be 6.0 to 7.5. Very strongly acidic reactions have several negative impacts on the soil and plant system. At such low reactions, several microelements become very soluble and, when available in sufficient quantities, become phytotoxic. Additionally, large quantities of iron and aluminum are solubilized. The high soluble iron concentrations readily tie up the available soil phosphorus, producing severe phosphate deficiencies. Aluminum concentrations will reach concentrations which are toxic to plants. Some evidence suggests that, at reactions below pH 4.0, hydrogen ion toxicity on the plant root hair takes place.

Exchangeable sodium percentage (ESP) and/or sodium absorption ratio (SAR). Sodium has two potentially negative impacts in the soil system: first, it increases osmotic concentrations in the soil solution and second, it acts to disperse the soil, generally lowering infiltration and percolation rates. The result of both actions is to produce a soil which has greater moisture stress. ESP is not the same parameter as SAR, but both were designed to evaluate the amount of sodium in a sample. ESP levels greater than 15 are recognized in the Soil Taxonomy (Soil Survey Staff 1975) in the differentiation between the natric and argillic horizons. Combined with information on both clay content and type, the ESP values should be generally held to less than 15. Non-expanding lattice clay types such as kaolin do not as readily disperse with higher levels of sodium as the expanding lattice montmorillonitic types. The amount of sodium present in agricultural soils is important in dryland and irrigated crop production in the Northern Great Plains (Fig. 8). Soils having high sodium levels near the surface are not generally suited for irrigation. The depth of surface horizons overlying the natric horizon (>15 ESP), when present in the till soils of North Dakota, determines not only whether wheat can be grown on them but also is a good indicator of potential yield. The SAR determinations are more frequently encountered in guidelines because they can be done more quickly, at a lower cost, and have better reproducibility. The presence of significant amounts of sodium, greater than an ESP of 8, particularly in moderately fine to fine-textured soils, limits both the potential for crop production and the potential uses that can be made of the soil. In reclamation, such materials are of poor quality for minesoil reconstruction, and, when levels approach or exceed an ESP of 15, they must be considered toxic and not included in the plant root medium.

Electrical conductivity (EC) is a function of the soluble salt concentration in the soil solution (see Fig. 9). Higher conductivity levels indicate elevated concentrations of salts which in turn reflect higher osmotic concentrations limiting potential extraction of water from the soil solution by plant roots. The result is an increased aridity in the soil which adversely affects plant productivity and plant community composition. Sulfates and chlorides are the dominant anions. Sodium and, to as more limited extent, potassium, are the important cations. As an example, if the EC is less than 4

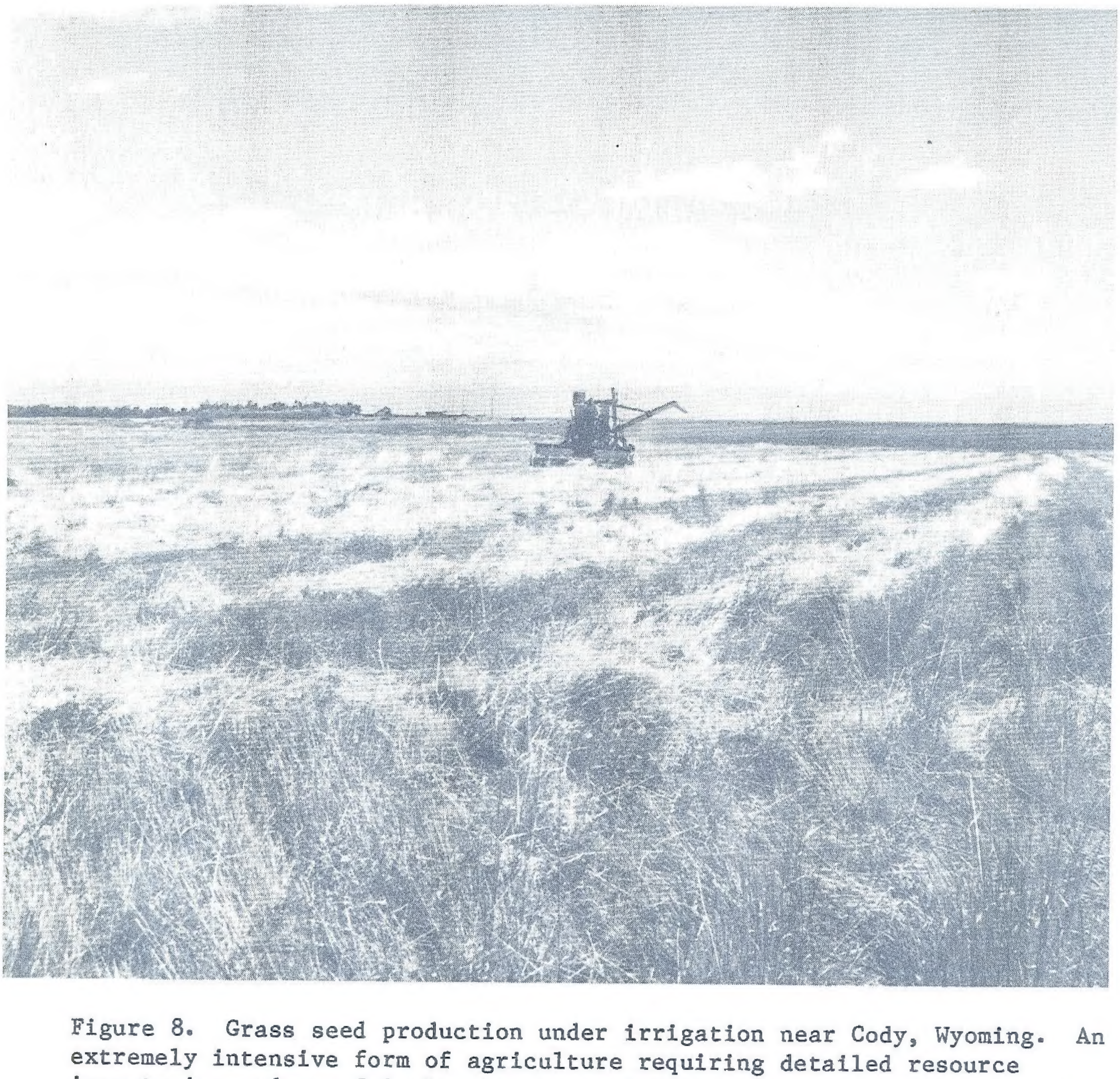


Figure 8. Grass seed production under irrigation near Cody, Wyoming. An extremely intensive form of agriculture requiring detailed resource inventories and careful planning to optimize production over the long term (photo--S. Fisher).

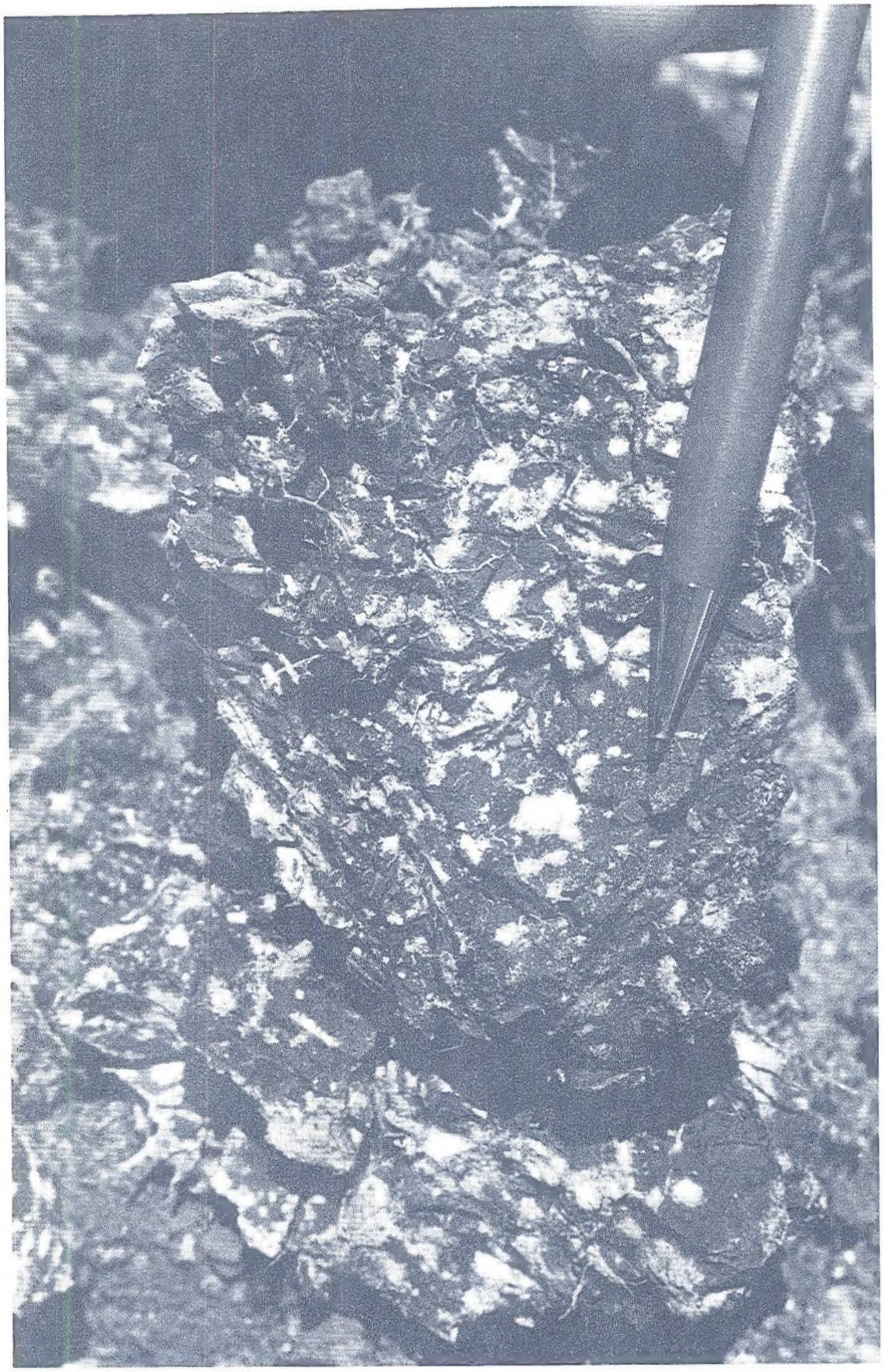


Figure 9. Soluble salt precipitation on shale plate faces resulting from soil-forming processes acting on shale parent rocks (Willow Creek Drainage, Valley County, Montana; photo--S. Fisher).

mmhos/cm, no crop is likely to suffer and, if the EC exceeds 8 mmhos, only salt-tolerant crops can be grown. Minesoils having EC values exceeding 8 to 12 may be very difficult to revegetate. The use of halophytes, plants generally occurring on and adapted to saline soils, would be required in revegetation efforts on minesoils above 12 mmhos/cm and potentially at lower levels depending upon other factors.

Calcium carbonate equivalents, the units of measurement for carbonate, present in the soil/overburden sample, often result in phosphorus deficiencies. The calcium carbonate precipitate is freuqently found in a fine silt-sized fraction which is highly erosive and additionaly higher levels tend to limit plant root development. Selecting materials for the immediate root zone should come from the decalcified portion of the soil on the soil solum. Higher levels of calcium carbonate would be acceptable in the lower horizons of the minesoil. The parameter is not often found in suitability guidelines for soil and overburden materials, but selective use of the analysis would provide significantly better selection of materials for minesoil reconstruction.

SOIL MORPHOLOGY AND DEVELOPMENT

The soils that occur on any landscape are products of the environment in which they occur. Numerous interactions occur between biotic and abiotic factors which control the development of the soil resource. The processes of soil formation are expressed in the resultant soil characteristics at any developmental stage of a soil. In 1941, Hans Jenny published his classical book, Factors of Soil Formation where he described five factors responsible for the formation or development of soils. Jenny theorized that 1) climate, 2) organisms (vegetation and microorganisms), 3) relief, 4) parent material, and 5) time were independent variables that together produce the soil system. In other words, for any given combination of the above factors, organisms, relief, parent material and time, the state of the soil system is fixed. Jenny (1941) suggested that only one type of soil will exist where all of these parameters were identical. However, if the degree or intensity of any of these factors change, the resultant soil system will differ. Malo (1974) described the distribution of organic matter across a hillslope. The results show a logarithmic increase from the shoulder to the toeslope position. Much of this difference can be attributed to the microclimate that can be found across a landscape segment. These microclimates are expressed by the higher organic matter levels in runon versus runoff positions across the hillslope segment. These differing amounts of effective precipitation were described earlier in terms of soil moisture relationships.

In the Central Great Plains, Muhaimeed (1981) determined the degree of horizonation and solum thickness across a landscape segment. Those studies showed an increase in solum thickness in runon positions across the landscape. This phenomena can be attributed to the interaction of microclimate and relief. Muhaimeed (1981) also showed, through his collection of profile descriptions, the different degrees of soil development that occur across a landscape. He concluded that on flat-lying, stable landscapes, a soil profile achieved the maximum expression of soil horizons. The study provides an excellent example of the interaction of soil-forming factors interacting on a soils development.

Malo's (1974) and Muhaimeed's (1981) findings can be of great significance to reclamation of disturbed areas. In each case, the effects of the soil-forming factors on the status or degree of development of a soil have been described. The more productive soils having higher organic matter contents can be found in runon positions on a landscape. In addition, it appears that these runon positions offer a larger volume of soil materials which can be used in the reclamation process. The long, relatively low gradient planar slopes widely found in today's landscape will not approach the diversity present in the natural system. Construction of differing types of minesoils and slopes will be required instead of even distribution of "topsoil" materials.

Natural soils have certain physical characteristics or features than can be used to describe the soil resource and evaluate its potentials and limitations. Many soil properties are assets while others are liabilities. For example, very low contents of clay within a soil can be a liability by having a limited water holding capacity, while moderate amounts can hold adequate amounts of water to supply the needs of the crops or other types of vegetation. Management scenarios should be developed that will enhance the characteristics of a soil which is adapted to the currently or proposed use and thereby mitigate any adverse reactions. This feature or characteristic can be referred to as a "soil quality." A land manager must be aware of the most important qualities of soils to fully use this resource, yet preserve these qualities for future generations. To identify the important qualities of a soil, a basic understanding of the observable characteristics of soils is needed.

Each soil body, as defined earlier, has features or characteristics making it similar to or different from other soils. These features are expressed in soil horizons or layers which generally occupy positions roughly paralleling the soil surface.

To better comprehend some of the basic properties of soils, the following definitions are included:

Soil Profile--A soil profile may be described as a "vertical exposure of a surficial portion of the earth's crust that includes all the layers that have been altered during the period of soil formation. . ." (Boul et al., 1973).

Soil Horizon--A soil horizon is "a layer of soil approximately parallel to the soil surface, with characteristics produced by soil-forming processes" (Soil Survey Staff 1975).

A hypothetical sketch of a soil profile, illustrating several of the soil horizons, has been included as Figure 1. Major horizons shown in the figure are designated A, C, C, and R and are described and technically defined later. Each major soil horizon can be divided into several subhorizons (e.g., A_1, A_{21}, B_{21}, and B_{22}). A soil horizon is classified according to the soil-forming factor. In addition, horizons can be separated into organic and mineral horizons. Such separations are dependent on the amount of mineral/organic fractions contained within the soil.

The major soil horizons are defined as follows (Soil Survey Staff 1975):

Organic Horizons-"O"-Organic horizons of mineral soils are those that have been formed from organic litter derived from plants and animals deposited on the soil surface.

Mineral Horizons-"A"-Mineral horizons consist of either horizons of organic matter accumulation formed or forming at or adjacent to the surface, or horizons that have lost clay, iron or aluminum with resultant concentrations of quartz or other resistant minerals of sand or silt size.

Mineral Horizons-"B"-Horizons in which the dominant feature or features is one or more of the following: 1) an illuvial concentration of silicate clay, iron, aluminum or humus, alone or in combination, 2) a residual concentration of sesquioxides or silicate clays, alone or mixed, that has formed by means other than solution and removal of carbonates or more soluble salts, 3) coatings of sesquioxides adequate to give conspicuously darker, stronger or redder colors than overlying or underlying horizons in the same sequum but without apparent illuviation of iron.

Mineral Horizons-"C"-Mineral horizons or layers, excluding bedrock, which may or may not be similar to the material from which the solum is presumed to have formed, relatively little affected by pedogenic processes, and lacking properties diagnostic of A or B but including materials modified by 1) weathering outside the zone of major biological activity; 2) reversible cementation, development of brittleness and high bulk density; 3) gleying; 4) accumulation of calcium or magnesium carbonate or more soluble salts; or 5) cementation by calcium or magnesium carbonate or more soluble salts.

Mineral Horizon-"R"-Underlying consolidated bedrock, such as sandstone or limestone. If presumed to be like the parent rock from which the adjacent overlying layer or horizon was formed, the symbol R is used alone. If presumed to be unlike the overlying material, the R is preceded by a Roman numeral denoting a difference in materials (II R).

The above definitions describe the major soil horizons that may be found within a single profile. The extent of horizonation is an expression of the development of a soil. As a result of this development, the number and type of horizon present are highly variable. This can be attributed to differences in parent material, relief, climate, vegetation and time acting together upon a soil. As a result of this variability, many soil profiles lack some of the major horizons described above. Any major horizon may contain subdivisions within one or more of the major horizons. These subdivisions are based on observable characteristics produced by interaction of the biotic and abiotic factors (see Fig. 1). Examples of observable characteristics which are subject to change are: soil color, soil texture, structure, and parent material. In addition, presence or absence of salts such as calcium carbonate or gypsum are criteria for major horizon subdivisions.

In an attempt to show the interaction of the soil-forming factors on soil genesis, development or formation, the Soil Survey Staff (1975) developed the concept of diagnostic soil horizons which are used in the Soil Taxonomy. These horizons can be used in an interpretive sense for evaluating, in a general way, the quality of a soil. The following discussion deals with the major diagnostic horizons, both surface and subsurface, of soils in the Western United States. The reader is explicitly cautioned that the following definitions are only abstractions and, therefore, Soil Taxonomy (Soil Survey Staff 1975) should be referenced for a complete and detailed definition.

The diagnostic horizons are divided into surface and subsurface horizons. The surface horizons are termed "epipedons" and consist of mollic epipedons and ochric epipedons which are the dominant epipedons in the region.

They are defined as follows:

(1) Mollic epipedon--A surface horizon that, when mixed to a depth of 17.5 cm (7 in.), contains 1% or more organic matter, with Munsell values

darker than 5.5 dry and 3.5 moist. Structure cannot be massive and hard. Base saturation is greater than 50% and the epipedon is not naturally dry more than three months per year (Boul et al. 1980).

(2) Ochric epipedon--A surface horizon that is light in color, with color values being less than 5 dry and less than 3.5 moist, contains less than 1% organic matter, or is hard or very hard and massive when dry or dry more than three months per year (Boul 1980).

Subsurface diagnostic horizons that are typically found in soils of the Western United States include the following:

(1) The argillic horizon in general is a B horizon that has a greater percentage of clay than some overlying horizon. The clay increase is formed by illuviation or downward movement in the profile and there should be evidence of illuviation argillians or clay skins (Boul 1980).

(2) Calcic horizons have a subsurface layer which has a secondary accumulation of carbonates, usually calcium or magnesium in excess of 15% calcium carbonate equivalent and contains at least 5% more carbonate than an underlying layer (Boul 1980).

(3) The cambic horizon is a subsoil horizon that shows evidence of physical and/or chemical alteration. Physical alteration includes: 1) movement of soil particles by frost, roots or animals to such an extent to destroy most of the original rock structure, or 2) aggregation of the soil particles into peds (structure). Chemical alteration includes: 1) hydrolysis of some of the primary minerals to form clays and liberate sesquioxides, or 2) solution and redistribution or removal of some carbonates. Cambic horizons are sometimes referred to as structural (physical alteration) and/or color (chemical alteration) B horizons.

(4) The natric horizon is a special kind of argillic horizon. It has, in addition to the properties of the argillic horizon, prismatic, or more commonly, columnar structure in some part. The horizon has sodium adsorption rates of >13 (or 15% or more saturation with exchangeable sodium) in some subhorizons within 40 cm of the upper boundary.

(5) The gypsic horizon is a noncemented or weakly cemented horizon of enrichment with secondary sulfates that is 15 cm or more thick and has at least 5% more gypsum than the C horizon or the underlying stratum.

SOIL CLASSIFICATION

Historically, many types of soil and/or land classification systems have been developed. Each system was initially formulated for a specific purpose and, in many instances, expanded to uses for which it was never intended.

In the United States, the Soil Conservation Service has directed the soil survey effort. A system of soil classification known as the 1938 Soil Classification System was developed in this country and published in the Yearbook of Agriculture. Based on the soil development processes active in a given soil system, the processes were identified through the nomenclature of a specific soil type. For example, a "Podzol" soil showed that the process of podzolization was the dominant process in development of a given soil. Since the genesis of a soil had a dominant role in its classification, the system was effective in categorizing soils by soil processes as well as by geographic regions; however, it was limited in its interpretive capability.

The 1938 system was widely used for soil survey work throughout the United States until the 1960s when American pedologists developed a classfication scheme then known as the 7th Approximation (Soil Survey Staff 1960). That system became the basis for the current USDA Soil Taxonomy (Soil Survey Staff 1975). The 7th Approximation was extensively used and tested during the 1960s; the testing effort resulted in a number of modifications. In 1970, a draft of the current Soil Taxonomy was put to a field test; that document was used until the final publication of Soil Taxonomy in 1975. Significant revisions have been made in this system and adjustments will continue to take place.

During the period when traditional methods of soil classification were evolving, many other types of soil and land classification schemes evolved. Many of these classification schemes emerged to meet specific needs of a group or a particular government agency, such as the Bureau of Reclamation's Irrigated Land Use, Land Classification Scheme (1953). This scheme is based on a wide array of integrated factors consisting of soil, geologic, vegetative, hydrologic and economic criteria. This system has been used through the Western United States on large areas of private, Federal and Indian lands. The surveys provide detailed data on soil properties, ground-water levels, bedrock depth and type, and various other factors.

A wide array of soil classification systems exists outside of the United States (see Fig. 10). Several countries have consented to test and use the current Soil Taxonomy, while others have developed their own system of classification. This latter case can be exemplified in Canada, where the Canadian Soil Survey Staff developed the Canada Classification System (National Soil Survey Committee of Canada 1978) for use within their country. It was designed to meet the needs of the Canadian soil scientist and appears to be specific to those soil zones that occur within Canada and has little applicability outside of that region.

Presently, Soil Taxonomy (1975), the basic system of soil classification, is widely used in the United States. Each agency involved in soil resource inventories who are participating in the National Cooperative Soil Survey Program (except the Bureau of Reclamation) has accepted and used the system.

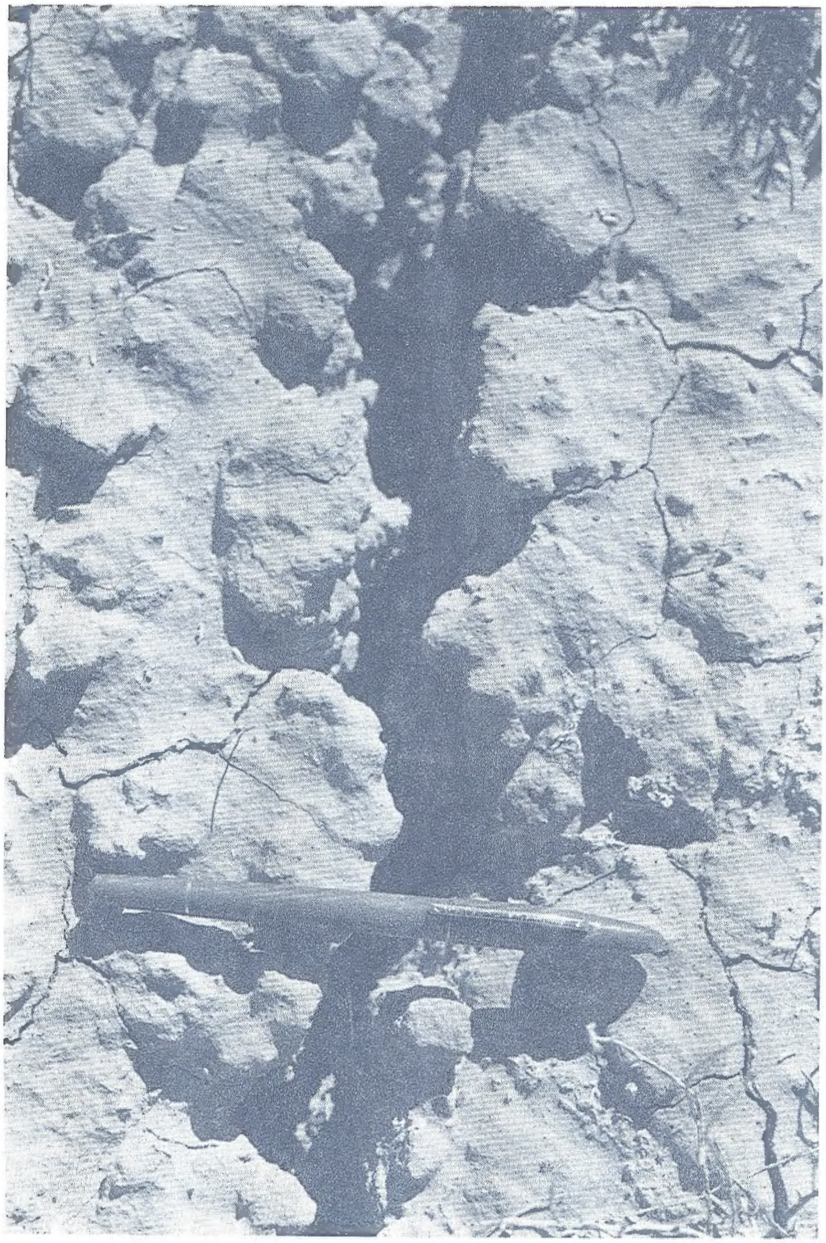


Figure 10. Strong vertical cracking occurs in soils classified as Vertisols or vertic intergrades. Characteristics such as these dominate many of the uses which can be made of these soils. Soils of this type are widely distributed in the temperate and tropical regions of the world (Arusha, Tanzania; photo--S. Fisher).

Briefly, Soil Taxonomy can be described as a hierarchial classification system that segments soils genetically, on the degree of soil development.

The hierarchy of the system is shown below; detailed definitions can be found in Soil Taxonomy (1975).

Order
Sub-Order
Great Group
Sub-Group
Family
Series

Many classification systems for organization and interpretation of soils information exist. A select few have been presented to show the diversity that exists in this area. It is key that the land manager, researcher or planner be aware of the classification systems that are used and use these systems only for what they were intended.

RELATIONSHIPS OF SOILS TO CIVILIZATION AND POPULATION GROWTH

The soil resource directly influences man and many of his activities. Much of the food that he consumes is produced from plant growth on this resource. As already described, soils are an extremely important component of the ecosystem and strongly influence the potential of such a system to produce wildlife, timber, range and crops. Agriculture, a dominant industry in the Western United States, is totally dependent upon this resource. Soils strongly influence many characteristics of the ecosystem, such as the quality and quantity of surface runoff and agricultural productivity.

The soil resource is a legacy which must be passed on intact from one generation of man to the next. It is a resource that has developed literally over thousands of years and one which can be destroyed in a few years when land is mismanaged or abused in other ways. The fertile soils of the Tigrus and Euphrates valleys enabled the production of flourishing civilizations. Yet these developments failed when elaborate drainage and irrigation facilities developed for the area were not maintained. The lessons of history are clear--careful use and maintenance of the soil resource is essential to the prosperity and survival of mankind. "If the soil is destroyed, then our liberty of choice and action is gone, condemning this and future generations to needless privations and dangers." (Lowdermilk 1953).

The importance of the soil resource to modern societies can be exemplified through a study of the rise and fall of past cultures. Civilizations have flourished, while the soil resource was intact and declined as the land lost its ability to produce. W.C. Lowdermilk (1975), in a historical study of agriculture, points out that soil erosion, deforestation, overgrazing, neglect, and in the conflicts between cultivators and herdsmen, were the primary causes of soil degradation and resultant civilization failures. Similar trends can be seen in modern times between nomadic tribes and farming communities in Africa. Lowdermilk's study emphasizes the need to protect and conserve this valuable resource.

The deterioration of the soil resource is not only a problem associated with the decline of past civilizations but it remains an active process in modern times. Soil erosion, while a natural process, has been dramatically accelerated through inappropriate use and abuse of the land in recent times. World demand for food has increased. Unfortunately, the degree and severity of soil erosion have also increased. In many countries, cultivation is being forced onto lands which have low productivity and which are erosion prone. For example, in many Third World countries, record rates of population growth have forced farmers to cultivate mountainous areas and lands having highly erratic precipitation patterns. Such areas require greater technological and managerial input and involve greater risks of soil erosion. Utilization of these marginal lands requires greater labor inputs; however, the technical expertise to develop and install conservation practices is not available. History has shown that once the natural cover is removed, the topsoil can quickly erode into adjacent valleys, where it silts streams, reservoirs and canals (Brown 1981). In the United States, the demand for food, feed and fiber, coupled with increased use of chemical fertilizers, large farm machinery and changing patterns of agricultural cropping, have caused many farmers to eliminate soil management practices that have historically helped conserve the soil resource. This abandonment has increased the potential for and amount of soil erosion as well as decreased the inherent ability of a soil to produce food and recover from minor abuse of the resource.

Deforestation, overgrazing, neglect and conflict in use of the soil resource are in evidence all around us; they contribute to the present extent of the world's major desert areas. As "marginal" soils in arid areas are continually abused, desert areas will undoubtedly become larger. This spread of the desert in response to man's abuse is generally termed "desertification." An example of this is described by Brown (1981): "Readings taken in the Sudan during 1958 and again in 1975 indicate the Sahara desert annexed some 90 to 100 kilometers during this 17 year period." Expansion of the Sahara is an extreme example of desertification but unquestionably makes a point. Misuse of soils of semiarid and arid environments can ultimately affect large areas of previously "stable" soils. The "desertifiction" phenomenon is evidenced on a large scale in Africa but occurs throughout the world on a smaller scale. As a result of the pressures made on the fragile soils of arid and semiarid regions, new desert areas are rapidly developing while present desert areas continue to spread. The only solution to this problem is proper use and management of the soil resource.

Soils are a product of the natural system but involve great lengths of time, particularly when compared to modern man's concepts of resource utilization. As mentioned earlier, the urbanite concept of the resource bears little resemblance to the real impact that it has on his life. In the rush to construct housing developments or miniranches/farms without considering natural resources, we have cost the American public millions of dollars through problems associated with inoperative septic systems, flooding and construction problems related to the high shrink and swell properties of bentonitic materials--as examples only. Planning to prevent problems of this sort is well within our capacities yet very rarely are factors such as these taken into consideration in selecting the area for development and the individual design of structures. Contrary to the Barnum philsophy that a sucker is born every minute, there are real societal costs associated with decisions of this sort. Soil surveys and their application in the planning and development process can alleviate many of these problems but only if the information is properly incorporated into the decisionmaking process. Secondly, most soil surveys were not made at sufficient detail to contribute to the design and construction of individual homes. The Soil Conservation Service which has had primary responsibility for such surveys in the United States has always maintained that on-site investigations must be used in making decisions where small parcels of land are involved or where significant capital investments were being made.

Food Production and Population Growth

Even a casual examination of world population growth and food production figures is a shattering experience, as human population exceeded 4.3 billion in 1979, with an annual increase of approximately 74 million people (1.7% rate). In perhaps more concrete terms, every five days we have to feed, clothe and educate another million people (Van der tak 1979). Stresses placed on natural resources, social services and interaction between people, as well as the political aspects of life by this type of uncontrolled growth are disastrous.

It should be painfully obvious to all that the understanding of the soil resource, its careful management and utilization, is the key to overcoming some of the short-term problems associated with the growth in numbers of people. Such understanding and actions are not the long-term solution to the problem. Simply stated, there are limits to growth in population as well as per-capita consumption of resources, particularly when one tries to place some value on the quality of life. Tables 5 and 6, modified from Haub and Hersler (1980), indicate the severity of the population growth problem and certainly suggest some of the disparity in "quality of life" which exists within regions and countries.

In the last two decades, food output has exceeded population growth. Most unfortunately, the bulk of the increase (1.4%) has come in the industrialized countries of the world where food was already abundant (Food and Agricultural Organization 1977). Food production in the developing countries has lagged well behind population growth, averaging something less than 1% (see Fig. 11). The data on absolute quantity of food produced being used here does not give a realistic picture of food production. Much of the gains in production in the developing countries has been in high calorie foodstuffs rather than in the critically needed protein. Secondly, the overall disparity still remains between the industrialized countries' caloric intake (3,380 calories/day) and the 2,210 calories/day found in the developing nations. The magnitude of this differential continues to broaden--the U.N. Food and Agricultural Organization's Survey Study (1977) in 44 developing countries found that daily per-capita supplies of calories declined between 1962 through 1963 and also declined from 1972 through 1974.

The lack of adequate food supplies, in association with other problems, produces a high infant mortality in many countries in the developing world. Kwashiorkor and marasmus are leading causes of infant mortality in the developing countries. Marasmus is an indication of overall undernutrition, while kwashiorkor results from protein starvation (Ehrlich and Ehrlich 1972).

TABLE 5. POPULATION AND SOCIOECONOMIC DATA FOR CERTAIN WORLD REGIONS REPRESENTING THE DEVELOPED AND UNDEVELOPED PORTIONS OF THE WORLD

Region or Country[1]	Population Estimate Mid-1980 (millions)[2]	Birth Rate[3]	Death Rate[3]	Rate of Natural Increase (annual, %)[4]	Number of Years to Double Population[5]	Population Projected for 2,000 (millions)[6]	Infant Mortality Rate[7]	Total Fertility Rate[8]	Population under Age 15 (%)	Population over Age 64 (%)	Life Expectancy at Birth (years)[9]	Urban Population (%)[10]	Projected Ultimate Population Size (millions)[11]	Per Capita Gross National Product (US$)[12]
WORLD	4,414	28	11	1.7	41	6,156	97	3.8	35	6	61	39	9,832	2,040
MORE DEVELOPED[1]	1,131	16	9	0.6	111	1,272	20	2.0	24	11	72	69	1,372	6,260
LESS DEVELOPED[1]	3,283	32	12	2.0	34	4,884	110	4.4	39	4	57	29	8,460	560
Eastern Africa	135	48	19	3.0	23	244	132	6.6	46	3	47	13	629	240
Middle Africa	54	45	20	2.6	27	87	167	6.0	43	3	45	29	218	300
Southwest Asia	98	40	12	2.7	25	164	117	5.8	43	4	56	46	281	2,280
Middle South Asia	938	37	16	2.2	32	1,422	137	5.5	42	3	51	21	2,566	180
Tropical South America	198	36	9	2.7	26	333	98	4.6	42	3	62	60	551	1,430
Northern Europe	82	13	11	0.1	476	84	13	1.8	23	14	72	74	90	6,140
Western Europe	153	12	11	0.1	918	158	12	1.6	22	14	72	82	163	8,970
Eastern Europe	110	18	11	0.7	102	121	23	2.3	23	11	71	59	135	3,670

Source: Haub and Heisler. 1980

Footnotes begin on the following page.

TABLE 6. POPULATION AND SOCIOECONOMIC DATA OF A RANGE OF DEVELOPED AND DEVELOPING COUNTRIES OF THE WORLD

Region or Country[1]	Population Estimate Mid-1980 (millions)[2]	Birth Rate[3]	Death Rate[3]	Rate of Natural Increase (annual, %)[4]	Number of Years to Double Population[5]	Population Projected for 2,000 (millions)[6]	Infant Mortality Rate[7]	Total Fertility Rate[8]	Population under Age 15 (%)	Population over Age 64 (%)	Life Expectancy at Birth (years)[9]	Urban Population (%)[10]	Projected Ultimate Population Size (millions)[11]	Per Capita Gross National Product (US$)[12]
WORLD	4,414	28	11	1.7	41	6,156	97	3.8	35	6	61	39	9,832	2,040
Kenya	15.9	53	14	3.9	18	32.3	83	8.1	50	2	56	10	93.8	320
Somalia	3.6	48	20	2.8	25	6.3	177	6.1	44	2	43	31	17.0	130
Zaire	29.3	46	19	2.8	25	48.1	160	6.1	45	3	46	30	121.9	210
Kuwait	1.3	42	5	3.7	19	3.1	39	7.0	44	2	69	56	5.3	14,890
Laos	3.7	44	20	2.4	29	5.7	175	6.2	42	3	39	15	11.1	90
Japan	116.8	15	6	0.9	79	129.4	8	1.8	24	8	45	76	133.4	7,330
United States	222.5	16	9	0.7	99	260.4	13	1.8	22	11	73	74	265.5	9,700
Australia	14.6	16	8	0.8	86	17.9	12	2.1	27	9	73	86	18.5	7,920
Spain	37.8	17	8	0.9	75	43.9	16	2.6	28	10	72	70	50.0	3,520
Poland	35.5	19	9	1.0	71	40.9	22	2.3	24	10	71	57	46.8	3,660
Switzerland	6.3	11	9	0.2	301	6.4	10	1.5	22	13	73	55	6.8	12,100
El Salvador	4.8	40	7	3.3	21	8.6	51	6.0	46	3	62	39	13.7	600
Brazil	122.0	36	8	2.8	25	205.1	109	4.4	41	3	64	61	341.0	1,570

Source: Haub and Heisler. 1980.

Footnotes begin on the second following page.

Footnotes for Table 5 and Table 6

GENERAL NOTES

World Population Data Sheets of various years should not be used as a time series. Because every attempt is made to use the most recent and most accurate information, data sources vary and changes in numbers and rates from year to year may reflect improved source material, revised data, or a later base year for computation, rather than yearly changes.

Sources of data: Aside from population estimates and projections (see footnotes 2 and 6), number of years to double population (footnote 5), and per capita Gross National Product (footnote 12), most of the data in this Data Sheet were reported in the following United Nations (UN) publications: Demographic Yearbook, 1977 and 1978; Population and Vital Statistics Report, Data Available as of 1 January 1980, Statistical Papers, Series A, Vol. XXXII, No. 1; and World Population Trends and Prospects by Country, 1950-2000: Summary Report of the 1978 Assessment, ST/ESA/SER.R/33, 1979. Other sources were: U.S. Bureau of the Census, World Population: 1977, 1978, and World Population: 1979 (forthcoming); unpublished reports of the Census Bureau's Foreign Demographic Analysis Division; World Bank, Population Projections 1975-2000 and Long-term (Stationary Population), prepared by K.C. Zachariah and My Thi Vu of the Bank's Population and Human Resources Division, July 1979; Country Reports of the World Fertility Survey; official country publications; and sepcial studies.

Figures for the regions and the world: Population totals (columns 1 and 6) take into account small areas not listed on the Data Sheet. These totals may also not equal the sums of their parts because of independent rounding. All other regional and world figures are weighted averages for countries for which data are available.

FOOTNOTES

[1] The Data Sheet lists all geopolitical entities with a population larger than 200,000 and all members of the United Nations (UN) regardless of population size. Classification of "more developed" and "less developed" regions follows the latest (1979) practice of the UN. The "more developed" regions comprise all of Europe, North America (Canada and the United States), Australia, New Zealand, Japan, and the USSR. Cyprus, Israel, and Turkey, formerly included in the "more developed" region of Southern Europe, are now included by the UN with their region of location, Southwest Asia, and are thereby considered "less developed."

[2] Based on a population total from a very recent census or on the most recent official country or UN estimate; for almost all countries the estimate was for mid-1978. Each estimate was updated by the Population Reference Bureau to mid-1980 by applying the same rate of growth as indicated by population change during part or all of the period since 1970.

[3] Annual number of births or deaths per 1,000 population. For the more developed countries with complete or nearly complete registration of births and deaths, nearly all the rates shown pertain to 1977 or 1978. For most

less developed countries with incomplete registration, the rates refer to the 1975-80 period. These rates were used in the medium variant estimates and projections as assessed by the UN in 1978 (UN, World Population Trends and Prospects . . .). These figures should be considered as rough approximations only. Some estimates were obtained from published reports of the U.S. Bureau of the Census, the World Bank, the World Fertility Survey, government statistial offices, and special studies.

[4] Birth rate minus the death rate. Since the rates were based on unrounded birth and death rates, some rates do not exactly equal the difference between the birth and death rates shown because of rounding.

[5] Based on the current unrounded rate of natural increase and assuming no change in the rate.

[6] For most countries, projected by the Population Reference Bureau by applying the 1980-2000 growth rate implied by the UN medium variant projections to the country's estimated mid-1980 population total. For the United States, the projection shown is from the most recent Series II projection published by the U.S. Bureau of the Census. This projection assumes that birth rates in the U.S. will rise somewhat during the balance of this century unti a total fertility rate (see footnote 8) of 2.1 is reached.

[7] Annual number of deaths to infants under one year of age per 1,000 live births. For countries with complete or nearly complete registration of births and deaths, nearly all rates pertain to 1977 or 1978. For many less developed countries with incomplete registration, rates are the latest available estimates generaly obtained from the sources noted above.

[8] The total fertility rate (TFR) indicates the average number of children that would be born to each woman in a population if each were to live through her childbearing lifetime (usually considered ages 15-49) bearing children at the same rate as women of those ages actually did in a given year. A TFR of 2.1 to 2.5, depending upon mortality conditions, indicates "replacement level" fertility--the level at which a country's population would eventually stop growing (or declining), leaving migration out of account. Most TFR's shown here refer to the 1975-80 period and are from UN, World Population Trends and Prospects . . . .

[9] Average number of years a newborn child could be expected to live if current mortality conditions were to continue throughout his or her lifetime. For the more developed countries with reliable mortality data, nearly all estimates shown pertain to part or all of the 1970-77 period. For most of the less developed countries with unreliable mortality data, estimates refer to some part of the period since 1970 and were prepared by one of the following organizations: the UN Population Division; the Population Division of the U.S. Bureau of the Census; or the World Bank's Population and Human Resources Division. Estimates of life expectancy for most less developed countries should be considered as rough approximations only.

[10] Percentage of total population living in areas termed urban by that country.

[11] This column has been included in this year's edition of the Data Sheet in order to illustrate each country's potential population growth and the ultimate size that could eventually be achieved. These projections were prepared by K.C. Zachariah and My Thi Vu of the World Bank (Population Projections, 1975-2000 . . .) and are not forecasts of what will necessarily happen, but could happen as a result of "long run implications of recent trends under a series of highly stylized assumptions." Specifically, the projections assume that fertility in all countries will someday arrive at replacement level (a TFR then of about 2.1) and remain there. For less developed countries, this is assumed to occur in the middle of the 21st century in Africa and somewhat earlier in Asia and Latin America. For more developed countries the arrival at replacement level fertility is placed about the year 2000. This assumes that the TFR will increase to 2.1 by that time in the many developed countries where fertility is now below replacement level. The projections also assume that immigration will have no appreciable impact on the population growth of a particular country; this assumption tends to lower the "ultimate population" of the United States and a few other countries which can be expected to receive immigrants in the future. Several regional totals were adjusted by the Population Reference Bureau in order to agree with the geographical classifications used on the Data Sheet.

[12] Data refer to 1978 and are provisional. All data for individual countries are from the World Bank, World Bank Atlas: Population, Per Capita Product, and Growth Rates, 1979.

[13] Opinions vary widely on demographic measures for China. Those shown here come from official sources quoted in the Guangming Daily and People's Daily and UN sources noted above. Their accuracy is unknown. The projected population for 2000 shown here could be high in light of China's recently announced policy to encourage the one-child family and reduce population growth to zero by 2000.

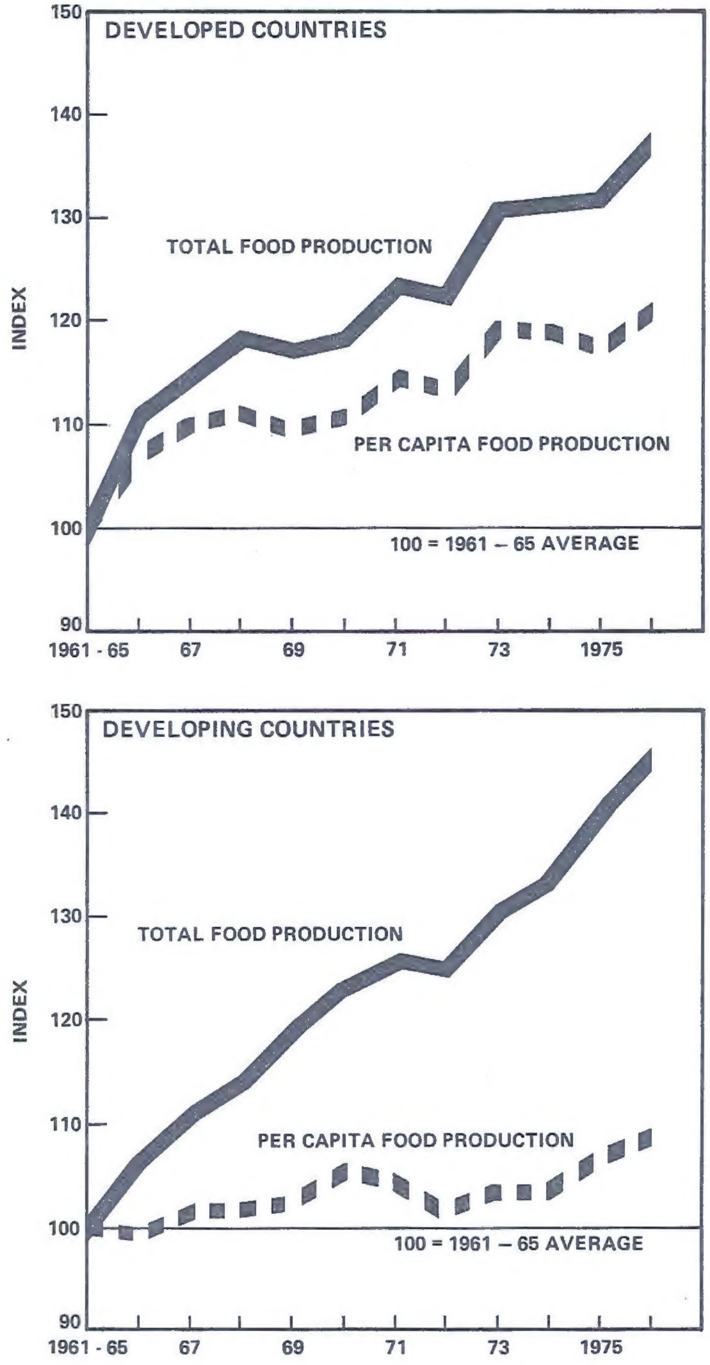


Figure 11. Total and per capita food production in developed and developing countries.

Source: Food and Agricultural Organization 1977.

The President's Science Advisory Committee Panel on the World Food Supply (1967) estimates that 50% of children 1 to 4 years old suffer from moderate protein-calorie malnutrition. Van der tak (1979) states "up to 50% of all young children in the developing world may be inadequately nourished--a deprivation likely to lead to lasting physical and mental damage for those who do survive." Diseases preventing less than full development of a child's mental facilities in an economic climate where educational opportunities are restricted are among the most repressive of conditions faced by the developed world.

The full impact of the growing disparity, both actual and in potential food production, between indiustrialized and developing countries, the high costs of increasing production on marginal soils, and differing stages of movement through the demographic transition by many countries are ominous. A country such as ours striving to truly develop peace in the world might be well advised to maintain its own soil resource and food production capacity and to export some of the fundamental skills related to soil management and agricultural development.

SURFACE COAL MINING, RECLAMATION AND LAND USE

The agricultural base on which a significant part of our country's economy has growing dependency is controlled to a large extent by the soil resource. Likewise, the success of a reclamation program is dependent upon the quality and quantity of the soil resource available and the care taken to reconstruct stable minesoils and landforms (Fig. 12). It follows that premine soil properties important to agronomic plant growth are also important to reestablishing natural plant communities and croplands to achieve optimum performance/production in the reclaimed minesoils.

The relationship between surface mining and long-term land use in the United States has been hotly debated over the last twenty years. In 1977 there were approximately 413 million acres of cropland and 987 million acres of grassland, pasture and range in the United States (USDA 1980). The reasons for concern over the land use, soil quality and reclamation issue are multifaceted. Sizable losses in irrigated lands have taken place through salinization and water logging. Costs associated with procurement of irrigation water have risen abruptly. Major losses of cropland to differing land uses continue and are even accelerating. Changes in the structure of American agriculture have intensified a serious soil erosion problem, resulting in significant losses from the cropland base--Cole (1982) suggests a staggering 3.2 million acres in Iowa, Illinois, Indiana, Ohio and Missouri. Two distinct aspects relating to surface mine reclamation emerge from looking at land use and management data for the country, that: 1) returning surface mined lands to similar productivity and capability will mitigate serious local impacts and start to stem the tide of land abuse in the United States, and 2) reconstruction of minesoils to a quality equal to or better than the premine, naturally occurring soils will mitigate or lessen many offsite impacts of coal mining.

All the Western coal lands are capable of and generally are meeting several land uses. Some of these uses include grazing, farming, recreation, watershed

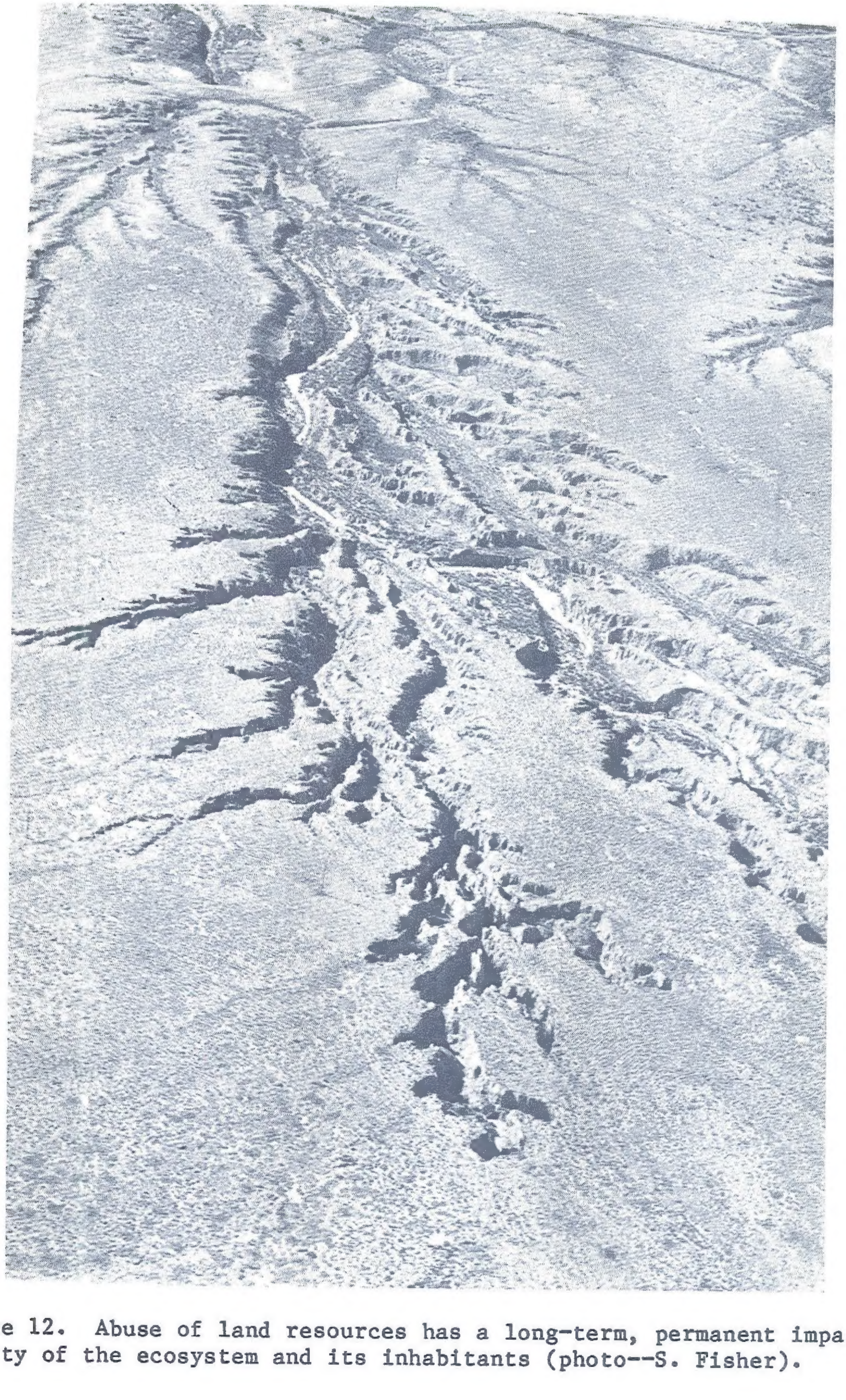


Figure 12. Abuse of land resources has a long-term, permanent impact on the quality of the ecosystem and its inhabitants (photo--S. Fisher).

management or wildlife habitat (see Fig. 13). In the process of surface mining, the ecosystem that has evolved over centuries is destroyed. Surface mining without reclamation in arid environments can remove land from productive use for literally thousands of years with associated intensification of offsite impacts on other resources. However, with successful reclamation, surface mining has the potential to become a quasi-transitional land use so that the ecosystem can potentially recover from and retain or perhaps increase its productivity in the region. The ecosystem will not be the same as in the premine landscape but, at times, it can have similar capabilities and productivity. In either case, the natural stability that once existed is reduced, because of the characteristics and relative instability inherent in the minesoil and the type of plant community it supports. As a result, reclamation efforts must be designed to meet the productivity, density, land capability, and stability needs of semiarid and arid environments.

The impact of surface mining will be very significant in the Northern Great Plains coal-producing regions--both economically and from the standpoint of natural resources and their utilization. Large land areas within the coal-producing regions potentially will be affected by surface mining and related conversion facilities. Impacts to the environment from such large-scale disturbances have devastating potential. The form of the coal development--mine mouth power generation, coal export or synfuel processing--will greatly influence the type and magnitude of the impacts. It is critically important that careful planning be exercised to reduce or mitigate the effects of this development on the total natural environment including soils, water, vegetation, wildlife and people.

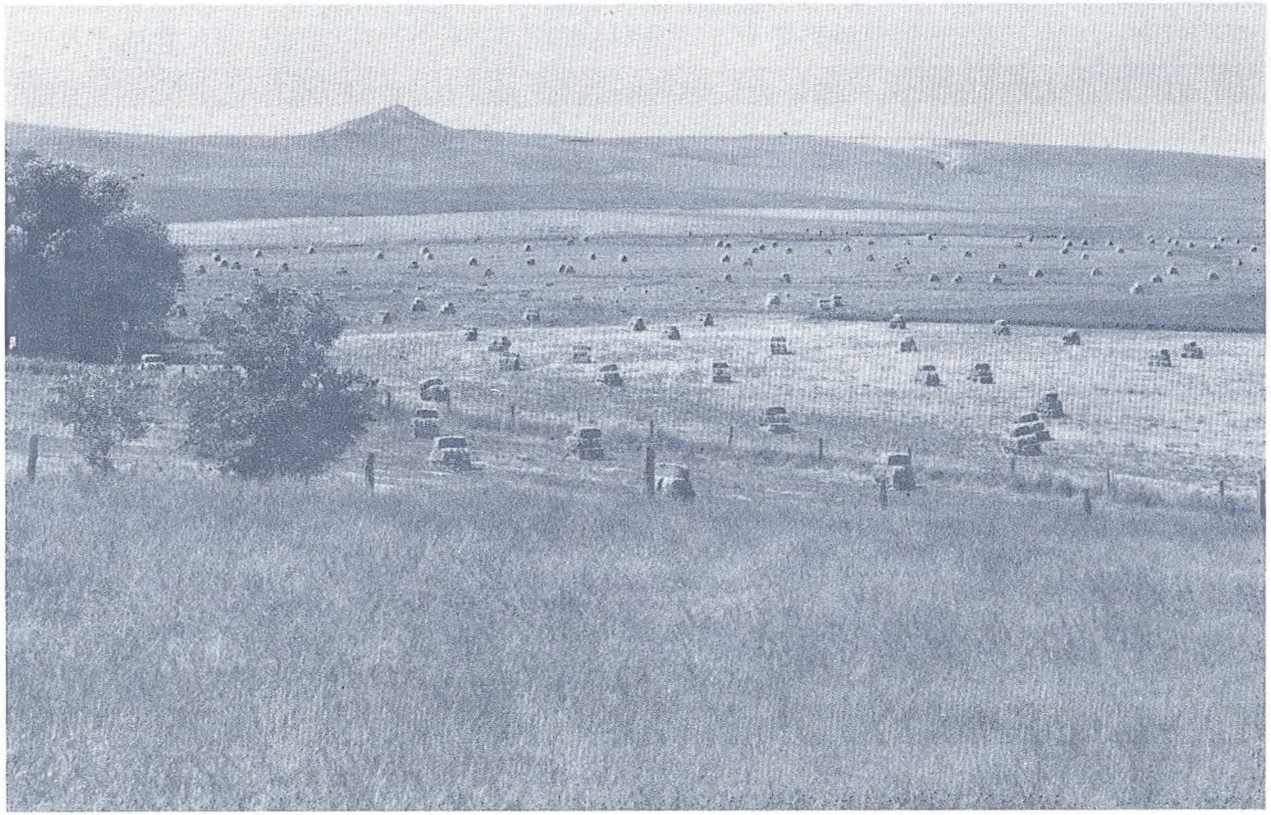


Figure 13. Multiple uses or potentials for land use--dryland wheat, hayland and rangeland near Recluse, Wyoming (photo--S. Fisher).

Surface Mining Impacts on the Soil Resource

Surface mining represents a long-term commitment of soil resources. At best, several years of production of native range, timber or agriculture are entirely or partially lost. The potential for successful long-term reclamation of surface-mined land has not been established in the Northern Great Plains. Infrequent but severe droughts, characterizing the regional climate (Ellison and Woolfolk 1937), could rapidly eliminate much or all of a new vegetative cover, producing a period of rapid soil erosion. The loss of the developing A horizon, which could take place during such abnormal precipitation patterns, could destroy the products of many years of soil formation.

Pronounced soil diversity characterizes the uplands of the Northern Great Plains, dominated by the Wasatch and Ft. Union formations. Highly contrasting soils can occur at 50-ft intervals or less in many of these ecosystems. Such diversity is lost as a result of mining and reclamation processes. Reclamation activities to date have produced a relatively homogeneous soil for the biotic community to develop on. A commensurate loss in biological diversity occurs in the plant communities found in such an area. The loss of resource diversity is of importance to wildlife and can be of importance to both livestock and cropping operations.

Development of the surface mine operation causes the existing soil resource to be destroyed and cannot be regained in its original form. Reclamation can accelerate the development of a new soil system, but the new minesoil characteristics cannot be predicted with current levels of reclamation planning. It is certain that the minesoil will not be the same as the premine soil. The new soil system (minesoil) will generally not support plant communities similar to either those existing or those potentially capable of developing on the premining soil system. The short-term capacity of the soil to support certain plant species such as Ponderosa pine (*Pinus ponderosa*), Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*), or Skunkbush (*Rhus trilobata*) apparently will be lost.

The surface mining of an area leaves slopes devoid of vegetation during the early stages of the revegetation effort, leaving soils largely unprotected from erosion. Frequently steeper and longer slopes are produced by mining activities--particularly in high wall reduction operations. Soil systems become disturbed, mixed and altered--biologically, chemically, and physically; as a result, they are more unstable, vastly increasing the risks of wind and water erosion of the soil resource. The length of time required to reach a level of slope/soil stability equal to similarly undisturbed native plant communities is unknown. Even if high levels of management are incorporated, the period necessary for recovery can only be estimated. Significant erosion or deposition increases will occur until a soil-binding type of permanent vegetative cover and some soil structure is established in the soil. The loss of soil materials through erosion contributes *greatly* to the degradation of water and/or air quality unless they can be confined to the site. Ecosystem components are not isolated but are fully integrated; each portion within the ecosystem responds to changes of other constitutents.

Soils that are removed by strip mining cannot be replaced as natural bodies in the landscape from which they were taken. Soils, as natural components of the landscape, have genetically related horizons that have developed over thousands of years concommitantly with the biotic community. The biogeochemical alterations within the soil that produced the genetically related soil horizons cannot be reproduced by man's reclamation of mine spoil areas. The soils in such areas have biologically active topsoil which was removed from a position in the mined area that was originally located over genetically related soil layers. Soils on reclaimed areas can probably be classified as Entisols, since they are considered as young soils. Subsequently, such soils will be modified by the biotic community and other soil-forming factors.

GENERAL DISCUSSION OF THE SOILS FROM COAL-PRODUCING LANDS OF THE NORTHERN GREAT PLAINS

The soil resources of the Northern Great Plains are the basis of much of its economic and social character. As described earlier, they provide the essentials from which the bulk of the reconstruction of the minesoils will take place. The following disucssion will separate these soils into two main groups--those developing from glacial and periglacial materials and the second group which is developing from the Fort Union and Wasatch formations. These two groups have been subdivided into four physiographic units--residual uplands and steep uplands, rolling uplands, alluvial fans and terraces, and flood plains and very low terraces.

Soils of the Coal-Producing Lands Dominated by Glacial Till Plains and Transitional Zones

The soils of this region are formed from a wide variety of parent materials including glacial till, periglacial deposits, aeolian (windblown) and the residual sedimentary Fort Union formation which underlies much of the area. Significant amounts of erosion of the till plains have taken place, resulting in redistribution of materials in the landscape--particularly deposition in the swales, terraces and flood plains. Drainages have cut back into the till plains providing for removal of surface waters. Many of these drainages support woody plant communities which are very significant to the distribution of wildlife and provide important cover for livestock. The glaciated areas are relatively flat, plain-like features which have had some dissection from eroding surface waters. As the mantle of till thins, the landscape will generally become more steeply sloping and frequently redistribution of the till materials will have taken place with secondary redeposition on the lower slopes and in the swales. The highly interbedded Fort Union dominates the upper slopes and ridges in such locations. A gradational characteristic between the deep till deposits and the Fort Union-dominated landscape exists in some locations, while in others it has a strong, definite line of demarcation.

The arid climate is reflected in generally shallow solum development, when compared with higher moisture regions, and limited amounts of chemical weathering of the soil. Grasslands dominate the region and the high base content of the plant material produced has maintained a relatively high base status in most of the soils. Commensurate with the high base status has been development of organic matter enrichments in the surface horizons resulting from the dominance of the grasslands. In general, the higher moisture portions of the region have produced more plant biomass, resulting in larger concentrations of soil organic matter. Important contrasts exist in these expression and development of these soil-forming factors between Oliver and Mercer counties of North Dakota (till and related parent materials) and southern Campbell County, Wyoming (residual sedimentary rocks).

The till plains are dominated by medium to fine-textured materials of mixed lithology which are high in carbonate, containing some characteristic stones and gravels. The clay fraction is often dominated by montmorillonite. When the soil content of clay reaches high levels (as an example--when clay contents exceed 40 percent), vertic intergrades are frequently developed. In some locations, the parent material contains moderate levels of sodium on the exchange complex and relatively high levels of salinity. Recessional waters have reworked significant amounts of the till materials, producing important terrace, swale and bottomland features. These materials are often of a stratified nature and coarser in texture than the original till. Windblown sediments are an important feature from two aspects--deeper deposits have allowed the development of soils from purely aeolian materials and, perhaps more importantly, the windblown materials have been deposited in a thin veneer and have subsequently been incorporated into soil solum through pedogenic activity.

Three orders of soils are important in the region--the Entisols, Aridisols and perhaps most important, the Mollisols. The latter are widespread in several of the coal-producing areas within the region and comprise some of the most agriculturally productive soils. The potentially prime farmland soils described by SMCRA (1977) and subsequently identified by the Soil Conservation Service, USDA, come from this order of soils. Mapping units of prime farmland have been identified by North Dakota State Office SCS-USDA. These soils are of critical importance to agriculture because they will produce harvestable quantities of grain under subnormal moisture and consistently out yield the Entisols found in some of the upland positions. Some elements within the coal mining industry arguing against application of prime farmland soil regulations have suggested that the only factor important in their increased productivity is their position in the landscape--therefore they receive additional effective moisture. Simplistic models such as these obviously overlook the importance of soil organic matter from both a soil fertility input as well as the greater depth of solum characteristics, the importance of soil structure, and available water holding capacities of such soils.

The Aridisols and Entisols are found in areas of lesser precipitation or in topographic positions receiving less effective precipitation. The Entisols are found on the steepest divides and ridges and infrequently in the flood plains where recent depositional materials have been deposited. The badland areas or other areas having large exposures of the Fort Union bedrock, such as the long escarpments serving the break between the uplands and drainage systems, are typically dominated by the Entisols. The Aridisols are far less important in these landscapes, for example, than in the Powder River Basin of Montana and Wyoming and are often found near or on the crests of the ridges where the amount of effective precipitation is limited. In most instances these soils represent intergrades to the Mollisols. Aridisols are generally less productive than the Mollisols because of their reduced fertility status, lesser available water holding capacity and position in the landscape resulting in a lowered total moisture status.

Soils of the residual ridges and steep uplands are dominated by the Entisols and differ only slightly from the soils found in the Fort Union-Wasatch region of the Northern Great Plains described later. In this location they are not as extensive and therefore not as important, nor do they have the full diversity found in the Powder River Basin. Table 7 lists some of the more important soils series in the respective soil-physiographic units being described.

Cabba-Cohagen Association (Mercer County, North Dakota; Wilhelm 1978)

Strongly sloping to very steep, shallow, well drained and somewhat excessively drained soils formed in material weathered from soft bedrock. These soils occur on a residual upland plain. The strongly sloping to very steep Cabba soils and Cohagen soils are on convex ridgetops, hillsides and side slopes along drainageways. The Cohagen soils generally are above the Cabba soils. They have a fine sandy loam surface layer and are somewhat excessively drained. The Cabba soils have a loam or silt loam surface layer and are well drained. The most extensive minor soils in this map unit are Williams, Zahl, Vebar, and Ringling soils. The nearly level to gently rolling Williams soils are on small glacial till plains between incised drainageways. They are above the Cabba and Cohagen soils on the landscape. The gently rolling to steep Zahl soils are on moraines and the upper side slopes along drainageways. The moderately sloping to strongly sloping Vebar soils are on the plane and convex, mid and lower side slopes below the Cohagen soils. The Ringling soils, which are shallow over porcelainite (scoria), are on the tops of knobs and hills and on the lower side slopes below the Cabba soils. Figure 14 illustrates the position of soils in the closely related Cabba-Cohagen-Rhoades soil association.

Morton-Daglum-Werner Association (Oliver County, North Dakota; Weiser 1975)

Nearly level, deep to shallow, well drained and moderately well drained, loamy soils. This association (Fig. 15) consists mainly of soils that formed in thinly stratified, soft shale and rock on the Fort Union Formation. It is on broad, residual plains that have long, smooth slopes. There are small areas that have a thin, patchy mantle of glacial till. Glacial stones and boulders are common over most of the association, and silicified stones are common to numerous in some places. Thin stratification of residual beds and an erratic glacial till mantle result in a complex soil pattern in many places. The

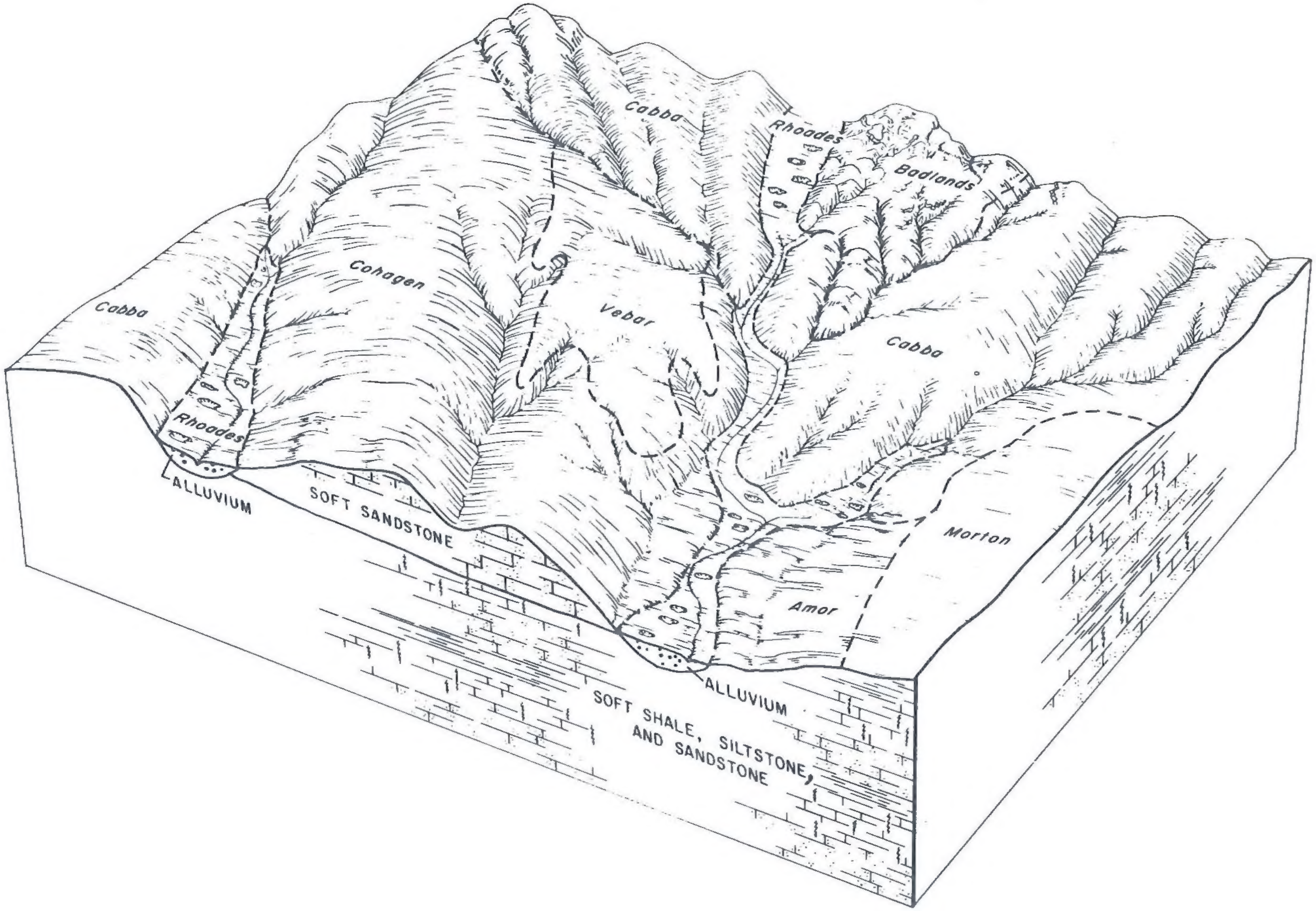


Figure 14. Typical pattern of soils and underlying material in the Cabba-Cohagen-Rhoades association similar to the Cabba-Cohagen association described herein (Dunn County North Dakota; Soil Survey Report 1982).

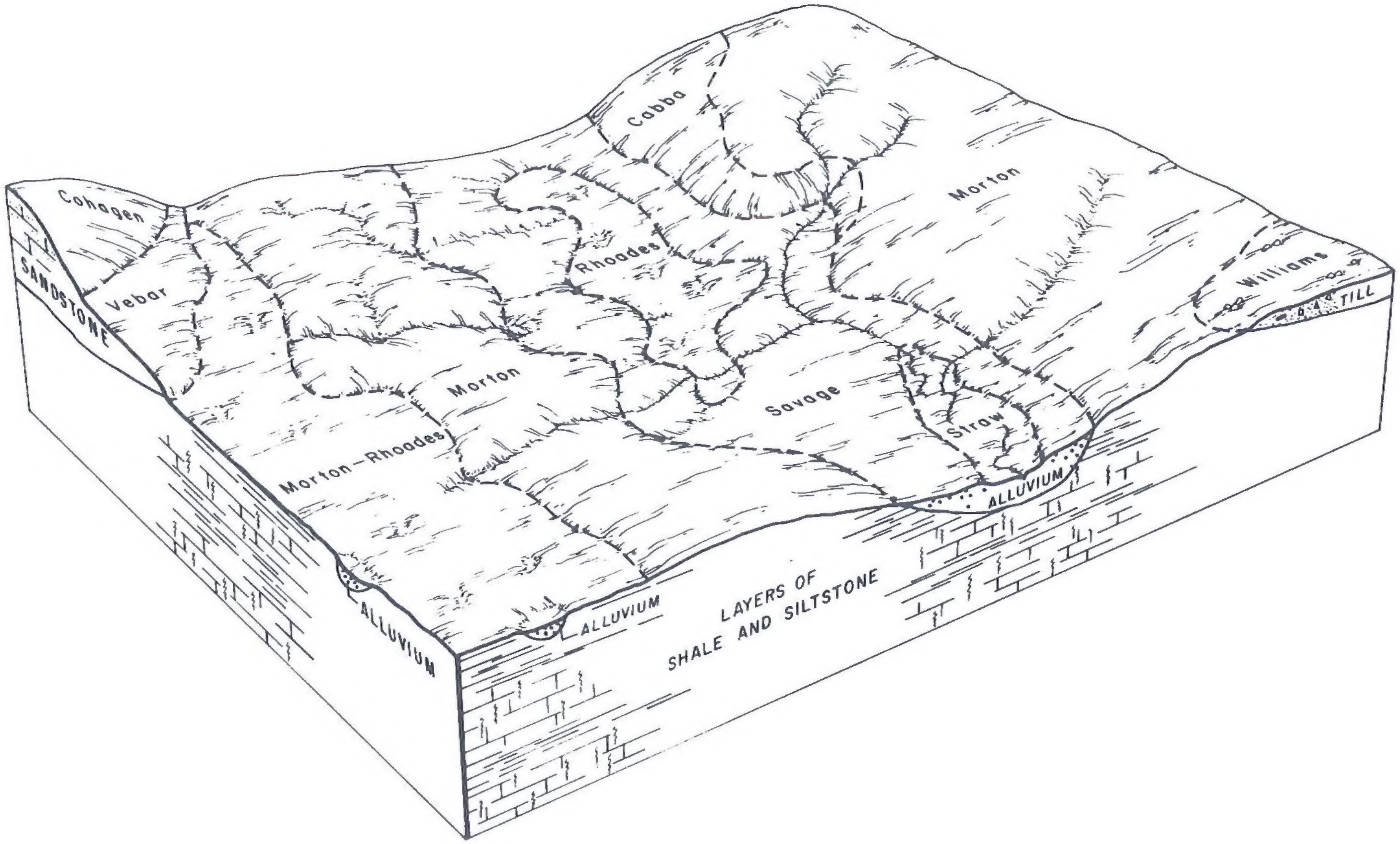


Figure 15. Typical pattern of soils and underlying material in the Morton-Rhoades-Savage association, similar to the Morton-Daglum-Werner association described herein (Dunn County, North Dakota; Soil Survey Report 1982).

Morton soils have plane and convex slopes with an underlying material of loamy shale or loamstones. Daglum soils have plane or concave slopes and are in areas of low relief, being underlain with stratified shale or alluvium. Werner soils occupy tops and crests of broad ridges and steep side slopes. In places they are on hilltops and upper slopes in areas of rolling topography. Regent soils are in landscape positions that are similar to those of Morton soils, but they are formed in strata of residual material that has a higher clay content. Rhoades, Belfield, and Daglum soils are in the same areas as the Regent soils. Amor and Sen soils have plane and convex slopes. Grail and Arnegard soils are in swales. Lawther soils are in swales or in nearly level to gentle plane areas. Williams soils are in patches within the residual plain and have plane or convex slopes. Zahl, Cohagen and Cabba soils are on hilltops and upper side slopes. Vebar and Cohagen soils are on lower side slopes.

Williams-Zahl Associations (Oliver County, North Dakota; Weiser 1975)

Nearly level to steep, deep, well drained, loamy soils. This association (Fig. 16) consists of glacial till plains where there has been little surface deposition of windblown silt or sand. Areas of the broad, undulating to rolling plains have some nearly level ground moraines and discontinuous, hilly recessional moraines. The glacial till is more than four feet thick in most places, but the wind-laid surface deposits are patchy and thin, except in a few places. The association is dissected by many drainageways and intermittent streams. Williams soils have convex slopes and are found on low swells, nearly level plane slopes and side slopes of ridges and hills. They are on low swells, nearly level plane slopes, and side slopes of ridges and hills. Zahl soils occupy the tops of knobs, hills, and ridges and steep side slopes of drainageways. Temyik soils are nearly level and are in areas where the loess mantle is more than 20 inches thick. Arnegard and Grail soils are in swales and drainageways. Tonka and Parnell soils are in potholes. Sen soils are on positions similar to those of Williams soils but in areas where the glacial till mantle is very thin or lacking. Werner and Cabba soils are on hills, ridgetops, and steep side slopes of drainageways where there is no glacial till.

Havrelon-Lohler Association (Mercer County, North Dakota; Wilhelm 1978)

Level, deep, well drained and moderately well drained soils formed in material weathered from alluvium. These soils are on the flood plain of the Missouri River. The level Havrelon soils occupy plane slopes, generally above the Lohler soils. They are well drained and have a silt loam surface layer. The level Lohler soils occupy plane and slightly concave slopes. They are moderately well drained and have a silty clay surface layer. The most extensive soils in this unit are the Banks, Dimmick, and Seroco soils. The Banks occupy plane and slightly convex slopes. The very poorly drained Dimmick soils are in the oxbows. The excessively drained Seroco soils are on convex slopes along the edge of the flood plain and in some areas on the flood plain.

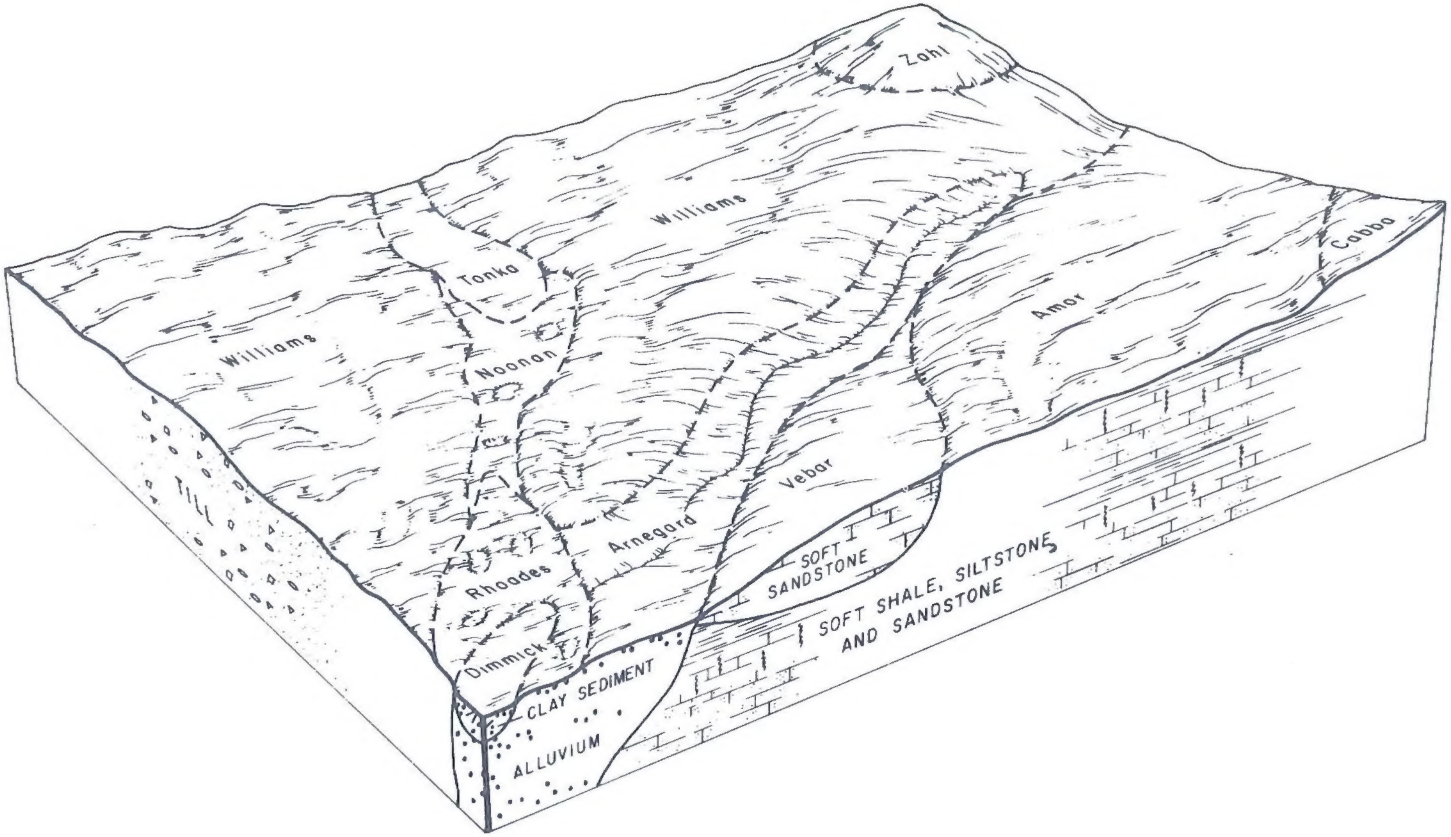


Figure 16. Typical pattern of soils and underlying material in the Williams-Amor-Arnegard association, similar to the Williams-Zahl association described herein (Dunn County, North Dakota; Soil Survey Report 1982).

TABLE 7. SOIL SERIES, CLASSIFICATION AND SOIL-PHYSIOGRAPHIC UNIT IN THE GLACIATED COAL PRODUCING AREAS

Residual Ridges and steep uplands

Cabba	(MT)	loamy, mixed (calcareous), frigid, shallow	Ustic Torriorthents
Cohagen	(ND)	loamy, mixed (calcareous), frigid, shallow	Typic Ustorthents
Ringling	(MT)	fragmental, mixed	Typic Haploborolls
Searing	(ND)	fine-loamy, mixed	Typic Haploborolls
Wayden	(ND)	clayey, montmorillonitic (calcareous), frigid, shallow	Typic Ustorthents
Werner	(ND)	loamy, mixed, shallow	Entic Haploborolls
Zahl	(ND)	fine-loamy, mixed	Entic Haploborolls

Rolling residual uplands

Amor	(ND)	fine-loamy, mixed	Typic Haploborolls
Lefor	(ND)	fine-loamy, mixed	Typic Argiborolls
Moreau	(ND)	fine, montmorillonitic	Typic Haploborolls
Morton	(ND)	fine-silty, mixed	Typic Argiborolls
Regent	(ND)	fine, montmorillonitic	Typic Argiborolls
Sen	(ND)	fine-silty, mixed	Typic Haploborolls
Vebar	(ND)	coarse-loamy, mix	Typic Haploborolls
Williams	(ND)	fine-loamy, mixed	Typic Argiborolls

Outwash and till plains,
Alluvial fans, and terraces

Arnegard	(ND)	fine-loamy, mixed	Pachic Haploborolls
Belfield	(ND)	fine, montmorillonitic	Glossic Natriboroll
Bowbells	(ND)	fine-loamy, mixed	Pachic Argiborolls
Bowdle	(SD)	fine-loamy over sandy, or sandy skeletal, mixed	Pachic Haploborolls
Cherry	(ND)	fine-silty, mixed, frigid	Typic Ustochrepts
Daglum	(ND)	fine, montmorillonitic	Typic Natriborolls
Dimmick	(ND)	fine, montmorillonitic, frigid	Vertic Haplaquolls
Falkirk	(ND)	fine-loamy, mixed	Pachic Haploborolls
Farland	(ND)	fine-silty, mixed	Typic Argiborolls
Flaxton	(ND)	fine-loamy, mixed	Pachic Argiborolls
Grail	(ND)	fine, montmorillonitic	Pachic Argiborolls
Grassna	(ND)	fine-silty, mixed	Pachic Haploborolls
Heil	(ND)	fine, montmorillonitic, frigid	Typic Natraquolls
Krem	(ND)	sandy over loamy, mixed	Typic Argiborolls

TABLE 7. (cont.)

Outwash and till plains, Alluvial fans, and terraces (cont.)

Lawther	(ND)	fine, montmorillonitic	Vertic Haploborolls
Lihen	(MT)	sandy, mixed	Entic Haploborolls
Linton	(ND)	coarse-silty, mixed	Typic Haploborolls
Mandan	(ND)	coarse-silty, mixed	Pachic Haploborolls
Noonan	(ND)	fine-loamy, mixed	Typic Natriborolls
Parnell	(MN)	fine, montmorillonitic, frigid	Typic Argiaquolls
Parshall	(ND)	coarse-loamy, mixed	Pachic Haploborolls
Rhoades	(ND)	fine, montmorillonitic	Leptic Natriborolls
Savage	(MT)	fine, montmorillonitic	Typic Argiborolls
Stady	(ND)	fine-loamy over sandy or sandy-skeletal, mixed	Typic Haploborolls
Tally	(MT)	coarse-loamy, mixed	Typic Haploborolls
Telfer	(ND)	sandy, mixed	Entic Haploborolls
Temvik	(ND)	fine-silty, mixed	Typic Haploborolls
Tonka	(ND)	fine, montmorillonitic, frigid	Argiaguic Argialbolls
Wabek	(ND)	sandy-skeletal, mixed	Entic Haploborolls
Williams	(ND)	fine-loamy, mixed	Typic Argiborolls
Zahl	(ND)	fine-loamy, mixed	Entic Haploborolls

Floodplains and very low terraces

Banks	(ND)	sandy, mixed, frigid	Typic Ustifluvents
Colvin	(ND)	fine-silty, frigid	Typic Calciaquolls
Harriet	(ND)	fine, mixed, frigid	Typic Natraquolls
Havrelon	(ND)	fine-loamy, mixed (calcareous), frigid	Typic Ustifluvents
Lallie	(ND)	fine, montmorillonitic (calcareous), frigid	Typic Fluvaquents
Lehr	(ND)	fine-loamy over sandy or sandy-skeletal, mixed	Typic Haploborolls
Lohler	(ND)	fine, montmorillonitic (calcareous), frigid	Typic Ustifluvents
Magnus	(ND)	fine, montmorillonitic	Cumulic Haploborolls
Makoti	(ND)	fine-silty, mixed	Pachic Haploborolls
Regan	(ND)	fine-silty, frigid	Typic Calciaquolls
Straw	(MT)	fine-loamy, mixed	Cumulic Haploborolls
Trembles	(MT)	coarse-loamy, mixed (calcareous), frigid	Typic Ustifluvents
Velva	(ND)	coarse-loamy, mixed	Fluventic Haploborolls

Soil-Physiographic Units of the Coal-Producing Wasatch and Fort Union Formations

Soils forming on the highly interbedded sedimentary Fort Union and Wasatch Formations range very widely in their chemical and physical characteristics. For a detailed description of the variation inherent in these formations, refer to the article by Brown (1983) in this publication. The physical properties of the parent rocks or materials range in texture from sand to clay and in color from the strong reddish (5YR) hues of the scoria or porcelainite beds to the yellow (2.5Y or 5Y) hues of the stratified sandy shales and shales on to the lithochromic materials having black or nearly black colors derived from the lignitic shales. Most of the strata contain free lime--they are calcareous and some are significantly influenced by salinity or alkalinity. With few exceptions the alkalinity and salinity problems are most pronounced in soils developing in slope wash or alluvial materials. Several of the Fluvents or flood-plain soils have levels of salinity or alkalinity sufficiently high to impair their use for cropland or hayland.

The dominant soils belong to the Entisols and Aridisols, although some Mollisols are found where greater effective precipitation has occurred. The latter soils are frequently intergrades to the Aridisols in contrast to the Mollisols described earlier developing on the till plains of North Dakota. Some of the more deeply weathered soils may be remnants from more mesic climates (Curry 1968). The depth of the solum and organic matter contents are less than in many of the North Dakota soils. In the residual uplands of the region, the most striking feature of the soil resource is its complexity and diversity. Fisher (1966) reported on the range of soils encountered along transects on the University of Wyoming-Gillette Agricultural Research Station east of Gillette, Wyoming. The complexity of soil distribution in the landscape is primarily due to the stratified nature of the bedrocks, development of a rolling topography with considerable vertical relief due to historic erosional patterns and the in-situ development of soil profiles rather than formation in long deep deposits of slope wash sediments, where mixing of a variety of sediment sources would have taken place.

Pedologically interesting shallow soils developing on shale or lignitic shales which are moderate to strongly acid in reaction occur in several of the counties in Montana, Wyoming and North Dakota. The first official series belonging to the acid reaction class to be recognized in the Western United States is the Dilts series from North Dakota. From a reclamation standpoint, the soils developing from the clinker beds (often termed porcelainite or scoria, although inappropriately) are of particular interest. The series which are shallow over bedrock have limited potential because of their depth, but the moderately deep and deep series have a tremendous utility and potential to alleviate surface erosion problems in the postmine landscape. Their high fertility status and content of coarse materials make these materials ideal for use in highly erosive areas in the postmine landscape. The soils are frequently characterized as having high organic matter contents and 20 to more than 60 percent of channery materials which consist of flat platy pieces of baked shale. They are very resistant to erosion both in their natural condition and in the reconstructed soils.

Reverting to the discussion on soil development, the relief and parent material or bedrock are primary determinants of the kinds of soils found in the Fort Union and Wasatch landscapes. The long, steeply sloping residual ridges, and, to a limited extent, the steeper portions of the rolling uplands are dominated by bedrock outcrops, shallow (10" to 20" over bedrock) and very shallow (0" to 10") Torriorthents--soils having only A and C horizons. Slopes will range from 30 to greater than 60 percent. Surface water runoff takes place very rapidly, carrying with it much of the soil-forming products. Some colluvial movement of materials takes place because of the steep slopes. Table 8 lists some of the dominant soil series found in portions of the landscape.

The Powder River Breaks country in Campbell, Sheridan and Johnson Counties of Wyoming are characteristic of the steeper soil-physiographic unit. Interestingly, far less is known about these soils and their characteristics than about the better developed and more agriculturally important soils of the region. Many of the soil series found on these areas have not been recognized to date, yet the knowledge of the chemical and physical properties of such soils is very important in reclamation planning and studies relating to surface hydrology and water quality. In addition to the lack of importance in agricultural production, the study of these areas has been hampered by the lack of appropriate analytical procedures and difficulties in separating parent rock from parent material.

Ringling-Cabba-Midway Association (Powder River Area, Montana; Parker 1971)

Sloping to steep or hilly; shallow slaty loams to clay loams underlain by shale; on uplands (see Fig. 17). This association occurs mainly in the western, southwestern and central parts of the survey area. It occupies high narrow divides, steep southerly slopes that have exposures of shale, rounded red-capped buttes, mesa remnants, and slopes covered with grass or trees. The red caps of the buttes are red shale beds of burned-over coal beds. The association is drained by a branching pattern of U-shaped valleys, swales, and drainageways.

The rolling uplands are an important soil-physiographic feature of the region (see Fig. 18). The soils are generally moderately deep (20" to 40" over bedrock) and deep but have either developed insitu from weathered substrates from the sedimentary parent rock or from very local slope wash materials. Depending upon the effective precipitation, parent materials and climatic regime, the Camborthids, Haplustolls, Haplargids, Argiborolls, and Natriargids would dominate. The saline and alkaline types of soils are more frequently encountered in the deep soils and lower on the slopes where concentration of the soluble materials would take place. The dominant textures are medium to fine and the presence of argillic horizons on the lower gradient slopes is not uncommon. Stephens (1975), in the soil survey of the southern part of Johnson County, Wyoming, describes the following association which typifies some of the associations prevalent in this unit:

TABLE 8. SOIL SERIES, CLASSIFICATION AND SOIL-PHYSIOGRAPHIC UNITS IN THE FORT UNION AND WASATCH AREAS

Residual ridges and steep uplands

Cabba	MT	loamy, mixed (calcareous), friged, shallow	Typic Ustorthents
Castner	MT	loamy-skeletal, mixed	Lithic Haploborolls
Dilts	ND	clayey, montmonillonitic, acid, friged, shallow	Ustic Torriorthents
Elso			
Epsie	MT	clayey, montmonillonitic (calcareous), mesic, shallow	Ustic Torriorthents
Lismas	MT	clayey, montmonillonitic (calcareous), mesic, shallow	Ustic Torriorthents
Midway	MT	clayey, montmonillonitic (calcareous), mesic, shallow	Ustic Torriorthents
Orella	NE	clayey, montmonillonitic (calcareous), mesic, shallow	Ustic Torriorthents
Ringling	MT	fragmental, mixed	Typic Haploborolls
Samsil	SD	clayey, montmonillonitic (calcareous), mesic, shallow	Ustic Torriorthents
Shingle	WY	loamy, mixed (calcareous), mesic, shallow	Ustic Torriorthents
Travessilla	NM	loamy, mixed (calcareous), mesic	Lithic Ustic Torriorthents
Wibaux	WY	loamy-skeletal over fragmental, mixed, nonacid, mesic	Ustic Torriorthents

Rolling residual uplands

Absarokee	MT	fine, montmorillonitic	Typic Argiborolls
Barvon	MT	fine-loamy, mixed	Entic Haploborolls
Bidman	WY	fine, montmorillonitic,	Ustollic Paleargids
Briggsdale	CO	fine, montmorillonitic, mesic	Ustollic Paleargids
Cushman	MT	fine-loamy, mixed	Borollic Haplargids
Dast	MT	coarse-loamy, mixed (calcareous), frigid	Typic Ustorthents
Doney	MT	fine-loamy, mixed (calcareous), frigid	Typic Ustorthents
Eltsac	MT	very-fine, montmorillonitic (calcareous), frigid	Vertic Ustorthents
Gaynor	CO	fine, montmorillonitic (calcareous), mesic	Ustic Torriorthents
Gystrum	WY	fine-salty, gypsic, mesic	Ustollic Camborthids
Kim	CO	fine-loamy, mixed (calcareous), mesic	Ustic Torriorthents
Maysdorf	WY	fine-loamy, mixed, mesic	Ustollic Haplargids
Pierre	SD	very-fine, montmorillonitic, mesic	Ustertic Camborthids
Razor	MT	fine, montmorillonitic, mesic	Ustollic Camborthids
Recluse	WY	fine, montomorillonitic, mesic	Ustollic Haplargids
Remmit	MT	coarse-loamy, mesic	Ustollic Camborthids
Renohill	WY	fine, montomorillonitic, mesic	Ustollic Haplargids
Searing	ND	fine-loamy, mixed	Typic Haploborolls
Terry	CO	coarse-loamy, mixed, mesic	Ustollic Haplargids

TABLE 8. (Cont.)

Alluvial fans and terraces

Abasher	MT	fine, montomorillonitic	Borollic Natrargids
Absted	WY	fine, montomorillonitic, mesic	Haplustollic Natrargids
Arnegard	ND	fine-loamy, mixed	Pachic Haploborolls
Arvada	WY	fine, montomorillonitic, mesic	Ustollic Natrargids
Ascalon	CO	fine-loamy, mixed, mesic	Aridic Argiustolls
Bew	MT	fine, montomorillonitic, mesic	Ustertic Haplargids
Bone	MT	fine, montomorillonitic Icalcareous), mesic	Ustic Torriorthents
Cherry	ND	fine-silty, mixed, frigid	Typic Ustochrepts
Colby	KS	fine-silty, mixed (calcareous), mesic	Ustic Torriorthents
Farland	ND	fine-silty, mixed	Typic Argiborolls
Farnuf	MT	fine-loamy, mixed	Typic Argiborolls
Gilt Edge	MT	fine, montmorillonitic, mesic	Haplustollic Natrargids
Heldt	WY	fine, montmorillonitic, mesic	Ustertic Camborthids
Hesper	MT	fine, montmorillonitic, mesic	Ustollic Haplargids
Keiser	MT	fine-silty, mixed, mesic	Ustollic Haplargids
Kyle	SD	very-fine montmorillonitic, mesic	Ustertic Camborthids
Lennep	MT	fine, montmorillonitic	Glossic Natriborolls
Limon	CO	fine, montmorillonitic (calcareous), mesic	Ustertic Torriorthents
Marias	MT	fine, montmorillonitic (calcareous), frigid	Ustertic Torriorthents
Nobe	MT	fine, montmorillonitic (calcareous), frigid	Ustic Torriorthents
Rhoame	WY	fine, montmorillonitic, nonacid, mesic	Ustic Torriorthents
Savage	MT	fine, montmorillonitic	Typic Argiborolls
Shaak	MT	fine, montmorillonitic	Abruptic Argiborolls
Thurlow	MT	fine, montmorillonitic, mesic	Ustollic Haplargids
Ulm	WY	fine, montmorillonitic, mesic	Ustollic Haplargids
Vananda	MT	fine, montmorillonitic (calcareous), mesic	Ustic Torriorthents
Wyarno	WY	fine, montmorillonitic, mesic	Ustollic Haplargids

Floodplains and very low terraces

Bankard	CO	sandy, mixed, mesic	Ustic Torrifluvents
Glenberg	CO	coarse-loamy, mixed (calcareous), mesic	Ustic Torrifluvents
Haverson	CO	fine-loamy, mixed (calcareous), mesic	Ustic Torrifluvents
Havrelon	ND	fine-loamy, mixed (calcareous), frigid	Typic Ustifluvents
Hysham	MT	fine-loamy, mixed (calcareous), mesic	Ustic Torrifluvents
Korchea	ND	fine-loamy, mixed (calcareous), frigid	Mollic Ustifluvents
Lohmiller	MT	fine, montmorillonitic (calcareous), mesic	Ustic Torrifluvents

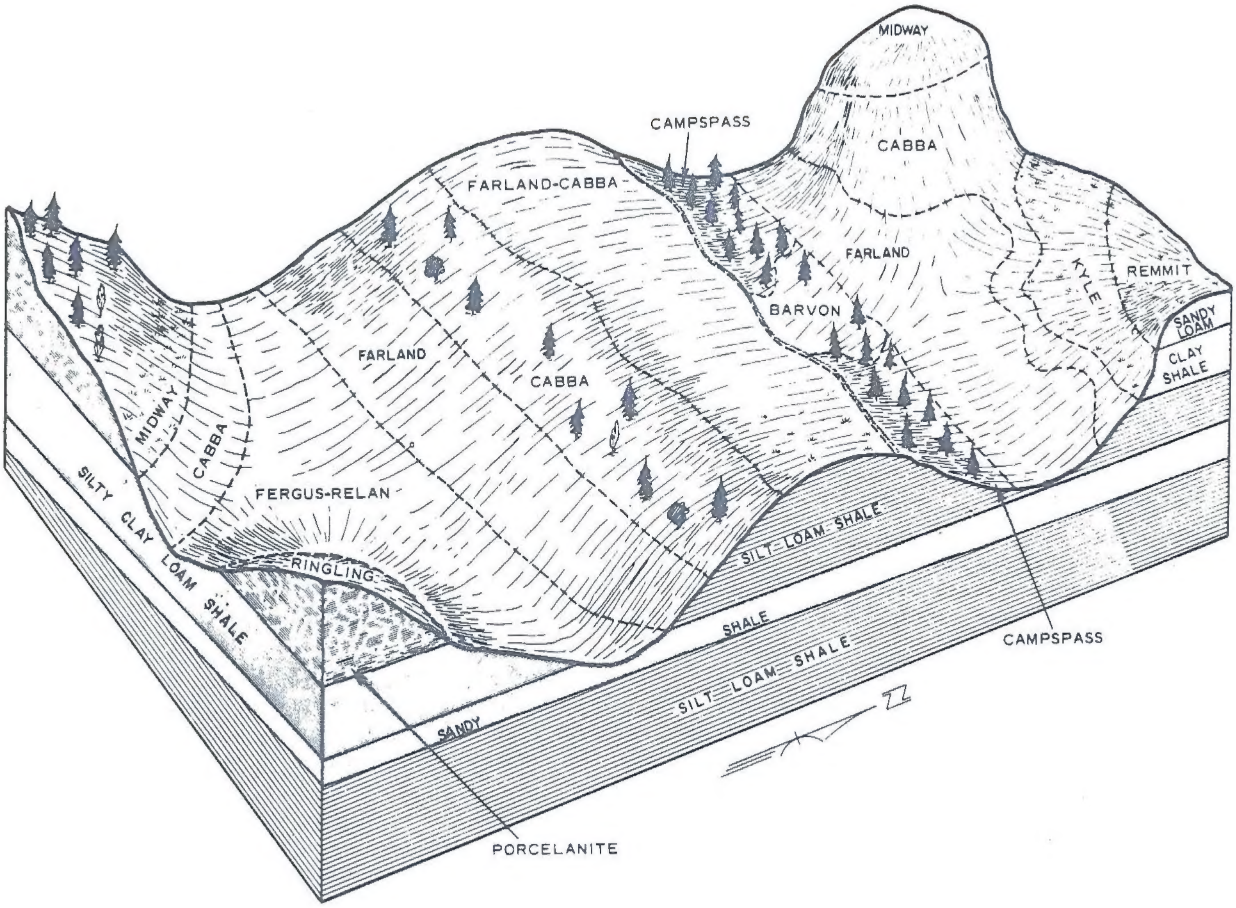


Figure 17. Farland-Cabba association in Powder River County, Montana (Parker 1971). Barvon: fine-loamy, mixed--Entic Haploborolls. Cabba: loamy, mixed, calcareous, frigid, shallow--Typic Ustorthents. Campspass: fine, montmorillonitic--Typic Entroborolls. Farland: fine silty, mixed--Typic Argiborolls. Fergus: fine, mixed--Typic Argiborolls. Kyle: fine, montmorillonitic, mesic--Usteritic Camborthids. Midway: clayey, montmorillonitic, calcareous, mesic, shallow--Ustic Torriorthents. Relan: coarse loamy, mixed--Typic Haploborolls. Remmett: coarse-loamy, mixed, mesic--Ustollic Camborthids. Ringling: loamy skeletal, mixed--Lithic Haploborolls. Source: Soil Survey of Powder River County, Montana (Parker 1971).

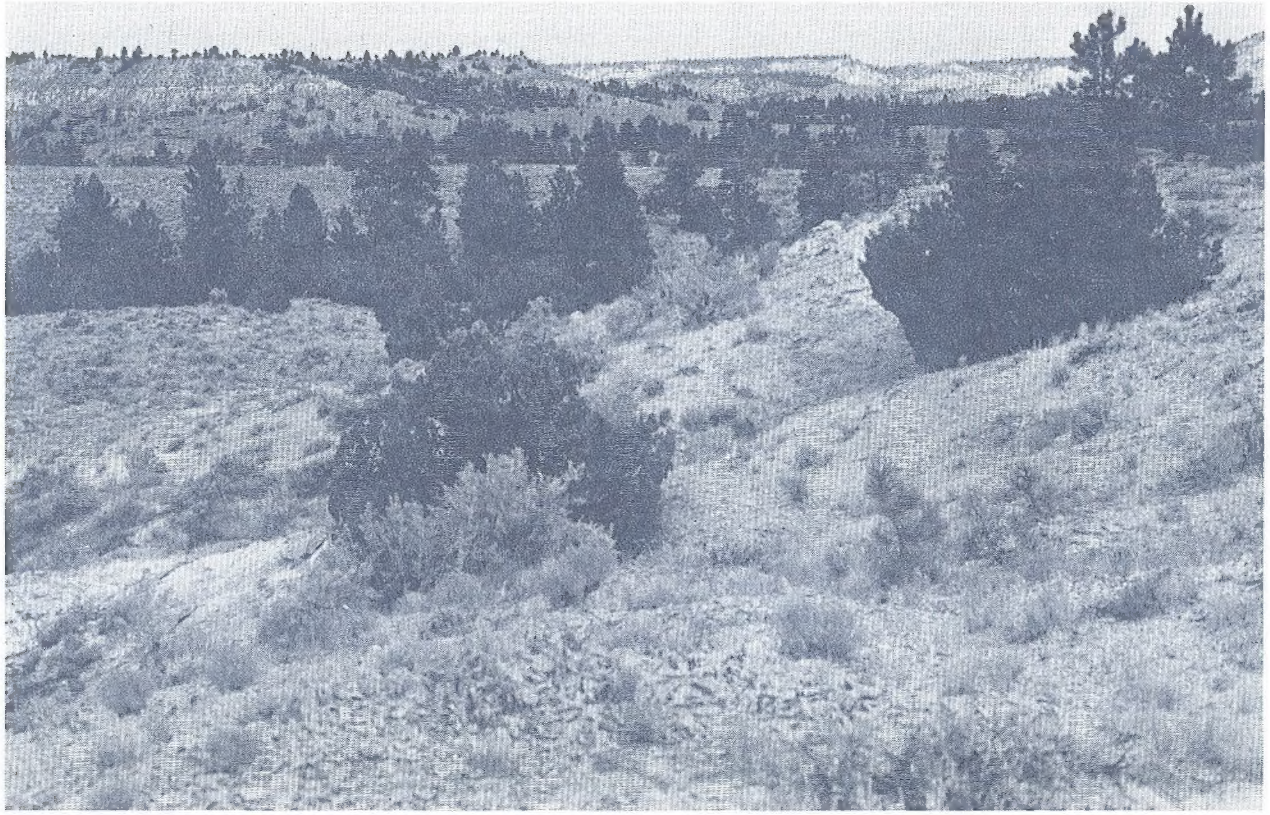


Figure 18. Uplands in the Fort Union-dominated areas near Ashland, Montana. The broad tabular divides in the foreground are dominated by Camborthids and Haplargids (photo--S. Fisher).

Briggsdale-Renohill-Cushman Association (Southern Part, Johnson County, Wyoming; Stephens 1975)

Moderately deep, nearly level to moderately steep sandy loams, fine sandy loams, and clay loams. This association consists of moderately deep, nearly level to moderately steep soils on uplands. The landscape is made up of rolling uplands that are dissected by numerous drainageways and small areas of gently sloping to sloping alluvial fans in valleys along intermittent streams. The bedrock is interbedded sandstone, siltstone, and shale; many soils formed in materials weathered from this bedrock.

Long alluvial fans and the sequence of terrace systems found in the region make up the third large soil-physiographic unit. The parent materials include those of local origin resulting from slope wash from the surrounding ridges and the older and more regional sediments found in the terrace systems. Some stratification of sediments is found particularily in the terrace soils. Frequently alkalinity or salinity problems affect both the productivity and potential uses of these soils. Soil texture ranges widely but the medium to fine textures appear to dominate, with the finer textures having shallower solums. The slopes are often of a long, wide planar type which have been dissected by active head-cutting channels moving upward from the primary channel. A description of an association from this landform follows and Figure 19 presents the soils in a different association but similar landscape.

Korchea-Farnuf-Savage Association (Big Horn County Area, Montana; Meshnick et al. 1977)

These soils are mainly on stream terraces and alluvial fans; they formed in alluvium. Deep, nearly level to steep, well-drained soils on fans, foot slopes, flood plains, and terraces.

This association consists of mostly nearly level to steep soils on flood plains, terraces, fans, and foot slopes. Korchea soils, on flood plains and fans, are nearly level to steep. Farnuf soils, on fans, terraces, and foot slopes, are nearly level to sloping. Savage soils, on fans, terraces, and foot slopes, are nearly level to strongly sloping.

The fourth soil-physiographic unit in the Fort Union and Wasatch formations area is that of the very recent terraces and flood plains. The range of soil series is much more limited because of the recent nature of the deposition and elimination of any major amount of soil formation. The dominant taxonomic units will be the Fluvents (see Fig. 20), Fluventic Haplustolls and Haploborolls and an occasional Orthent. Many of the soil-mapping units will contain elevated levels of salinity or alkalinity. The soils are generally developing in alluvial sediments derived some distance away, have carbonates at or near the surface and range widely in texture from moderately coarse to fine. Wetness and the presence of old oxbows and channels appreciably influence the potential use of some of these soils. The size or width of these channels varies greatly--from the broad flood plains of the Yellowstone valley

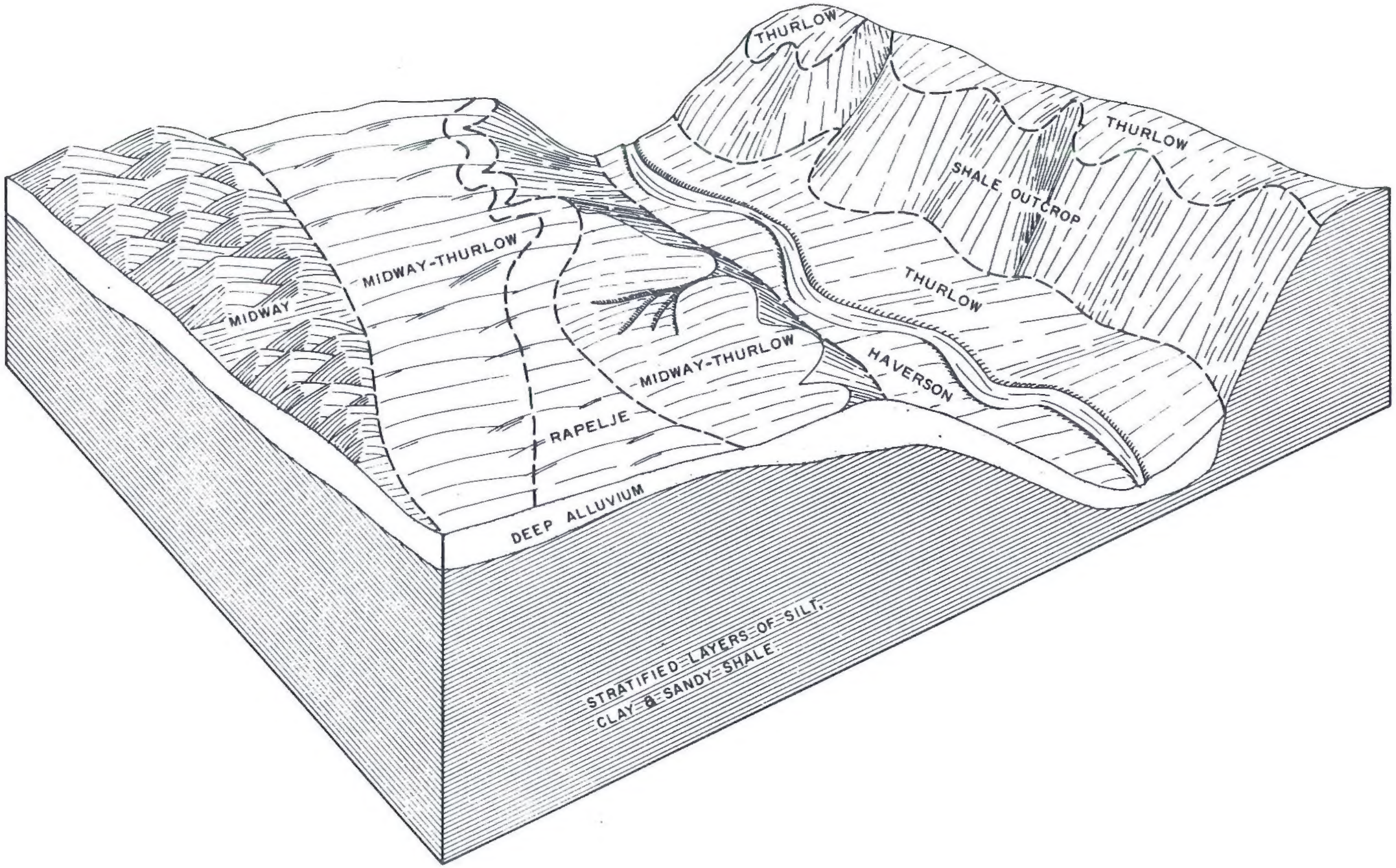


Figure 19. Relationship of soils in the Midway-Thurlow association to topography and underlying material. Haverson: fine-loamy, mixed, calcareous, mesic--Ustic Torriorthents. Midway: clayey, montmorillonitic, calcareous, mesic, shallow--Ustic Torriorthents. Rapeleje: fine-silty, mixed--Borollic Glossic Natrargids. Thurlow: fine, montnorillonitic, mesic--Ustollic Haplargids. (Source: Powder River County, Montana; Parker 1971).

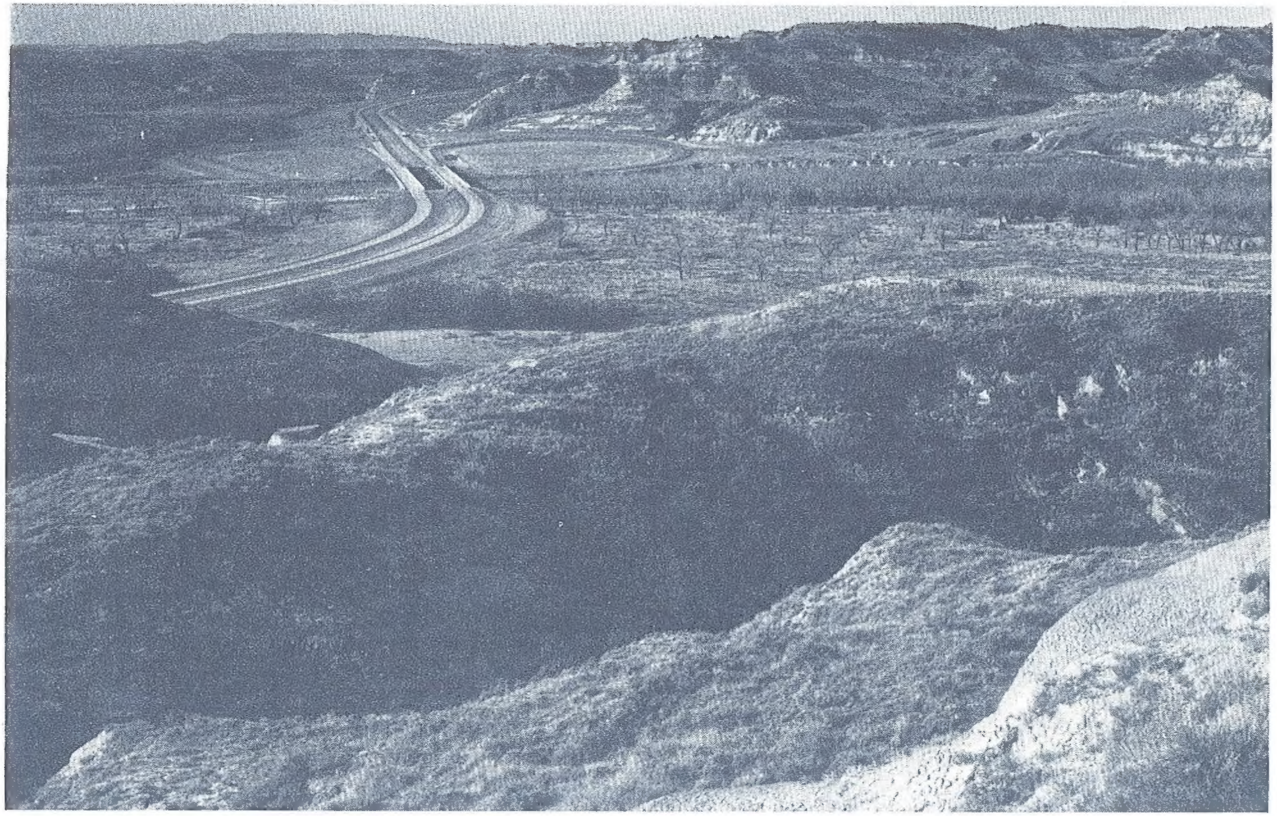


Figure 20. Broad alluvial flood plains in western North Dakota dominated by Fluvents such as the Havrelon and Lohler series (photo--S. Fisher).

which are several miles wide to the narrow flood plains of unnamed draws cutting back into the residual upland. These soils are crucially important as they provide much of the hay-producing potential for the surrounding ranches, if in native range they are extremely productive and third any mismanagement can result in serious soil erosion with direct impacts on water quality and downstream irrigation facilities.

Haverson Association (Yellowstone County, Montana; Meshnick 1972)

Level to gently sloping, deep loams that are underlain by loam and silt loam; on flood plains and terraces. This association of level to gently sloping soils is on the flood plains and terraces of the Big Horn River, the Yellowstone River, Clarks Fork of the Yellowstone River, and Pryor Creek. Sandy and gravelly soils occur along river channels and on islands (see Fig. 21). Seeped and wet soils occur in oxbows and meanders. On the flood plains the water table is within 60" of the surface, and the soils are flooded when snow melts in spring.

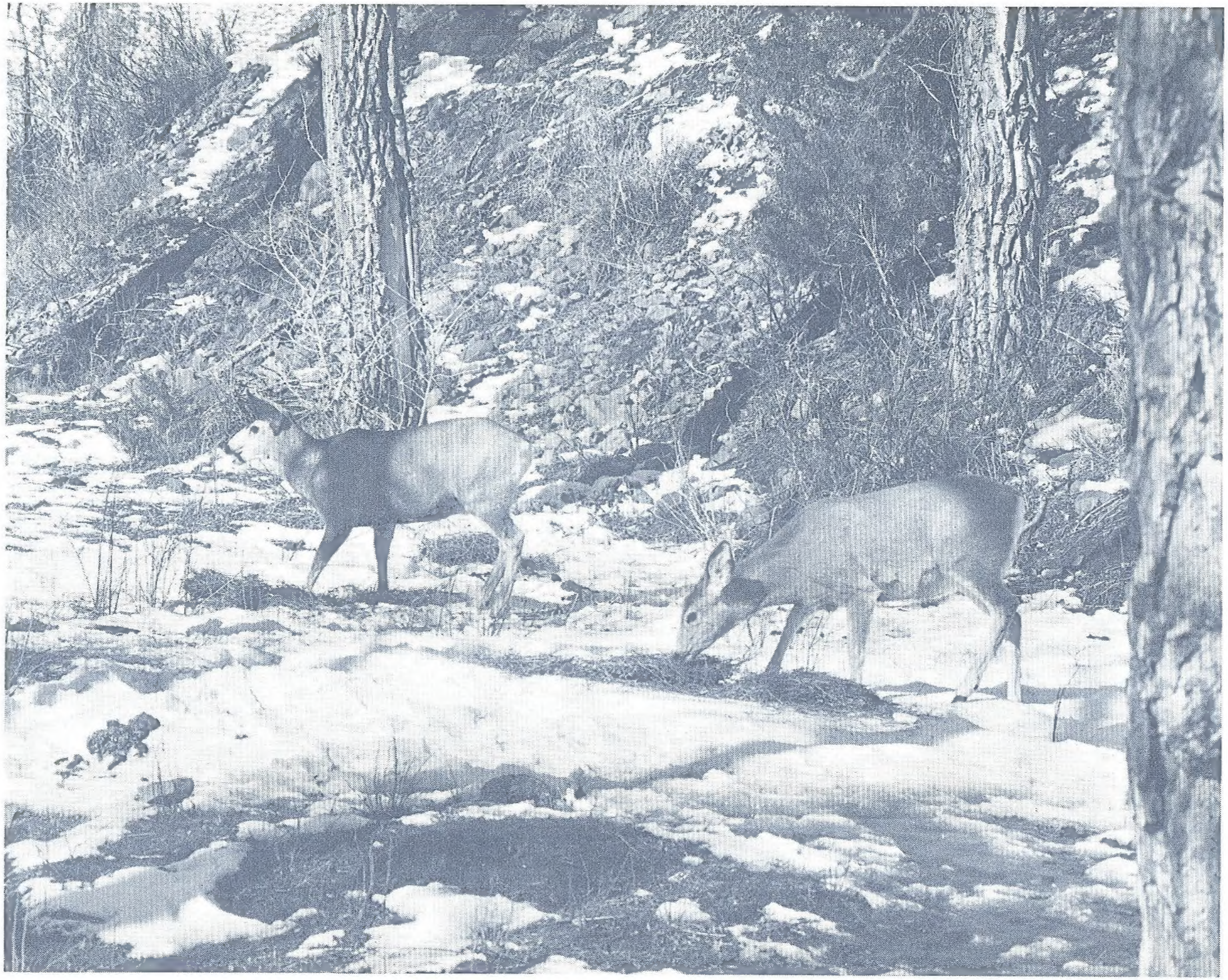


Figure 21. Mule deer utilizing forage in a small flood-plain area having a cottonwood overstory. The steeply sloping area behind the deer frequently characterizes landscapes in the region. The Haverson association described by Meshnick (1972) would encompass the Fluvents or alluvial soils occupying the foreground of the photograph (photo--Wyoming Game and Fish Department).

SOIL GUIDELINES AND PARAMETERS OF IMPORTANCE TO REVEGETATION SUCCESS

State regulatory agencies which have primary responsibility for most reclamation activities have developed guidelines for evaluating soil materials for use as topsoil and in some cases subsoil materials in the minesoil. Unfortunately, the early guidelines were developed based on studies related to "normal" agricultural soil-plant production studies. Many of the analytical techniques currently in use for evaluation of overburden and topsoil for reclamation are based on the analysis for deficiencies, while in this type of study the concern may well be with toxicities. Frequently, such tests have not been calibrated using field experimentation so that valid interpretation of these data can be made.

Soil chemical properties are generally much more rapidly analyzed for in the laboratory than physical parameters; additionally, the results of the chemical tests are generally much more reproducible than physical analysis. In recent years, once the extraction has been made, the rapidity of making routine analysis is so great that large quantities of chemical data are generated within very short periods of time (Soltanpour 1979). Significant problems do exist, however, in the correlation of laboratory data with plant response in the field, interpreting interactions between elements or compounds, and selecting extraction techniques. Massive reductions in reclamation research budgets during recent times have resulted in a lack of greenhouse and field testing of the results from laboratory analysis to allow proper interpretation of the data. The requirement for such a step has been well documented in agricultural soil fertility testing (Walsh et al. 1973). The final product from a soil and overburden testing program is the proper interpretation of the analytical data.

Soil survey and analytical information is, or should be, used in several ways in evaluating mine sites, developing mine plans and carrying out reclamation activities for strip mining operations. The establishment of baseline soil resource information for the description of the project ecosystem(s) is frequently the earliest use of this data. Such an inventory also represents a historical record of the resource which will be irretrievably lost as a result of a mining operation. Interpretation and evaluation of the survey data allows the reclamation planner to understand the existing land use and productivity potentials of a project site. Losses, tradeoffs and risks involved in the proposed action can then be properly evaluated. Soil resource information must be utilized in designing the layout of the ancillary facilities, not only to minimize the impact of their development, but to also lower construction costs.

Soil survey and laboratory data provide the baseline information upon which reclamation plans can be developed. This is particularly true in areas where severe soil limitations, chemical and/or physical, are frequently encountered. Some of the more important restrictions or concerns often include soil salinity, exchangeable sodium percentage, sodium absorption ratios, texture and high magnesium-to-calcium ratios. Other soil parameters of importance in reclamation include organic matter, calcium carbonate equivalents, stability of soil structure or aggregates, bulk density, and soil pH. The reclamation problems with soil materials having limitations such as those above are frequently compounded by the extreme shortage of suitable topsoiling materials.

Unfortunately, guidelines are often interpreted to be absolute rules by industry and to some extent by those authorities who developed them. All parties should be aware of the insecure basis upon which some guidelines are developed and errors that occur in soil inventory, sampling, and analysis should be used with some flexibility. Secondly, necessary research should be supported in order to modify such guidelines in the future. Some guidelines were adopted very early in response to state reclamation laws and a great deal has been learned during the intervening time. Several Western states, most notably Montana and Wyoming, are currently revising their guidelines for both soils and overburden. Considerable differences exist between states and academic authorities on what parameters should be analyzed for (see Table 9). Table 10 provides the draft revisions for soil and overburden suitability for use in reclamation in Montana. Wyoming draft guidelines currently circulating are found in Table 11. Appendix B contains the existing regulations for both states and other agencies/individuals.

Two distinct philosophies have dominated these developments: 1) to determine most of the soil parameters which have been demonstrated to influence plant growth and production being relatively confident in having tested for almost all of the characteristics which are thought important, and 2) to limit the analysis to those dominant parameters which have been found to control agriculture or reclamation activities in the region. The first scenario basically assumes the worst case philosophy and generally results in fewer mistakes being made early in reclamation programs but with higher costs, while the second results in less cost but greater risks being taken until more is learned about the primary soil and overburden hazards in reclamation. Wyoming and Montana are states which have taken the more conservative approach, while North Dakota has relied on less parameters being analyzed. Table 12 lists the guidelines currently being utilized by North Dakota.

Frequently it is necessary to select overburden materials which will provide a quality plant growth medium to meet the requirements of reclamation. To accomplish this task, analysis of the overburden materials must be carried out and properly interpreted. The methods of analysis utilized for soil samples are often not suited to the analysis of overburden or paralithic types of soil materials and the interpretation of such analyses remains a critical problem in today's reclamation. The selection of materials for constructing minesoils is primarily based on chemical properties. The single exception is that of soil texture which was described earlier in this paper as being of real significance in evaluating the suitability of soil materials for minesoil construction and plant growth.

Early in the history of soil science, rigorously extracting or totally analyzing samples were accepted procedures. Hydrochloric acid and various combinations of sulfuric and nitric acids were used in this type of extraction. These techniques have not been widely used in recent times because they do not reflect the availability of nutrients or microelements to plants. Currently, the basic extractant used for determining extractable cations in soil characterization studies is ammonium acetate. Historically, it, along with dilute acid solutions (0.1N HCl as an example) have been used for microelement soil extraction. Such techniques are not suited to soil samples having significant concentrations of calcium or magnesium carbonate. Soltanpour et al. (1977)

TABLE 9. COMPARISON OF SOIL AND OVERBURDEN ANALYTICAL PARAMETERS FOR STRIP MINE PLANNING AND RECLAMATION

	Draft EMRIA 1980		MT:DSL		WY:DEQ		ND: PSC	Miles City BLM District		FS-SEAM Thunder Basin		Old West Regional		EMRIA 1977		MSU Schafer		Omodt ND
	Soils	OB	Soils	OB	Soils	OB	Soils	Soils	OB	Soils	OB	Soils	OB	Soils	OB	Soils	OB	Soils
NO_3-N nitrate - nitrogen				X	X	X		X	X	X	X	X						
pH reaction	X	X	X	X	X	X		X	X	X	X	X		X	X	X		X
EC electrical conductivity	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
SAR sodium absorption ratio	X	X	X	X	X	X	X	X	X	X	X	X		X	X			
mechanical analysis	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X
$CaCO_3$ equivalent calcium carbonate	X						X			X	X	X						X
Saturation %			X		X	X				X	X	X			X	X		
CEC cation exchange capacity	X							X		X	X	X						
Coarse fragment >3"														X		X		
Avail. Water Cap. 1/3 and 15														X		X		
>2mm partials																		X
Organic matter	X				X	X	X			X	X	X						X
ESP exchangeable sodium %	X	X				X	X	X	X	X	X	X		X		X	X	
Na sodium	X	X	X		X	X		X		X	X	X	X		X			
K potassium	X	X	X	X	X			X		X	X	X						
Ca calcium	X	X	X	X	X	X				X	X	X			X			
Mg magnesium	X	X	X	X	X	X				X	X	X			X			
Available P phosphorus	X		X	X	X			X		X	X	X						

TABLE 9. (Cont.)

	Draft EMRIA 1980		MT:DSL		WY:DEQ		ND:PSC	Miles City BLM District		FS-SEAM Thunder Basin		Old West Regional		EMRIA 1977		MSU Schafer		Omodt ND
	Soils	OB	Soils	OB	Soils	OB	Soils	Soils	OB	Soils	OB	Soils	OB	Soils	OB	Soils	OB	Soils
Available K potassium	X		X		X			X		X	X	X						
N total nitrogen	X							X		X	X							
S sulfur					X			X		X	X							
NH_4-N ammonia nitrogen		X		X					X	X	X							
B boron	X	X	X	X	X			X	X	X	X				X		X	
Cd cadmium	X	X	X	X					X	X	X						X	
Cu copper	X	X	X	X				X	X	X	X						X	
Fe iron	X	X	X	X													X	
Pb lead		X	X	X		X			X	X	X						X	
Mn manganese	X	X	X	X						X	X						X	
Hg mercury		X	X	X					X								X	
Mo molybdenum	X	X	X	X				X	X	X	X						X	
Zn zinc	X	X	X	X					X	X	X						X	
As arsenic						X				X	X							
Se selenium	X	X	X	X	X			X	X	X	X						X	
Ni nickle		X	X	X					X	X	X						X	
Acid base potential					X	X												
Gypsum																		
Hydraulic conductivity									X									X
Bulk density																		
Clay mineralogy																		
Water slaking																	X	

Source: Fisher 1981.

TABLE 10. MONTANA PROPOSED SOIL AND OVERBURDEN GUIDELINES.

Unsuitability Criteria for Soil or Soil Substitutes

Parameter	Suspect Level[1]		
pH		< 5.5 > 8.5	
Conductivity (mmhos/cm)	Lift 1	> 4.0	
	Lift 2	> 4.0-8.0[2]	
Saturation percentage		> 85% < 25%	
Sodium adsorption ratio[3]		> 11.0	cl (≦ 35% c), scl, sil (≧ 20% c, ≧ 15% s), l (≧ 20% c)
		> 14.0	sl,l (< 20% c), sil (< 20% c, ≧ 15% s)
Exchangeable sodium percentage[3]		> 15.0	cl (≦ 35% c), scl, sil (≧ 20% c, ≧ 15% s), l (≧ 20% c)
		> 18.0	sl, l (< 20% c), sil (< 20% c, ≧ 15% s)
Boron		> 5 ppm	
Selenium		> 0.1 ppm	
Textural Class[3]		c, sc, sic, sicl (> 35% c, < 15% s), sil (< 15% s), si, ls, s	
Coarse fragments	Lift 1	> 20%[4]	
	Lift 2	> 35%[4]	

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[1] The suspect levels are to be used as a guide in evaluating the suitability of a soil material for reclamation. An evaluation should take into account the 'total system'. Interactive parameters may either nullify or verify the significance of a potential problem.

[2] The actual maximum acceptable salt level will depend on the plant species proposed in the revegetation plan and the potential for upward salt movement.

[3] See Figure 1.

[4] These values may vary depending upon the plant species proposed for revegetation in specific locations (e.g. a soil with a very high coarse fragment content throughout its profile may be completely salvaged if used for certain shrub or tree plantings).

Source: Harrington 1983.

TABLE 10. (Cont.)

Unsuitability Criteria for Overburden and Regraded Spoils

Parameter	Suspect Level[1]	
pH	< 5.5 > 8.5	
Conductivity (mmhos/cm)	> 4.0-8.0[2]	
Saturation percentage	< 25% > 85%	
Exchangeable sodium percentage[3]	> 15.0	cl (≦ 35% c), scl, sil (≧ 20% c, ≧ 15% s), l (≧ 20% c)
	> 18.0	sl, l (< 20% c), sil (< 20% c, ≧ 15% s)
Boron	> 5 ppm	
Molybdenum	> 0.5-1.0 ppm[4]	
Selenium	> 0.1 ppm	
Textural class[3]	c, sc, sic, sicl (> 35% c, < 15% s), sil (< 15% s), si, ls, s	

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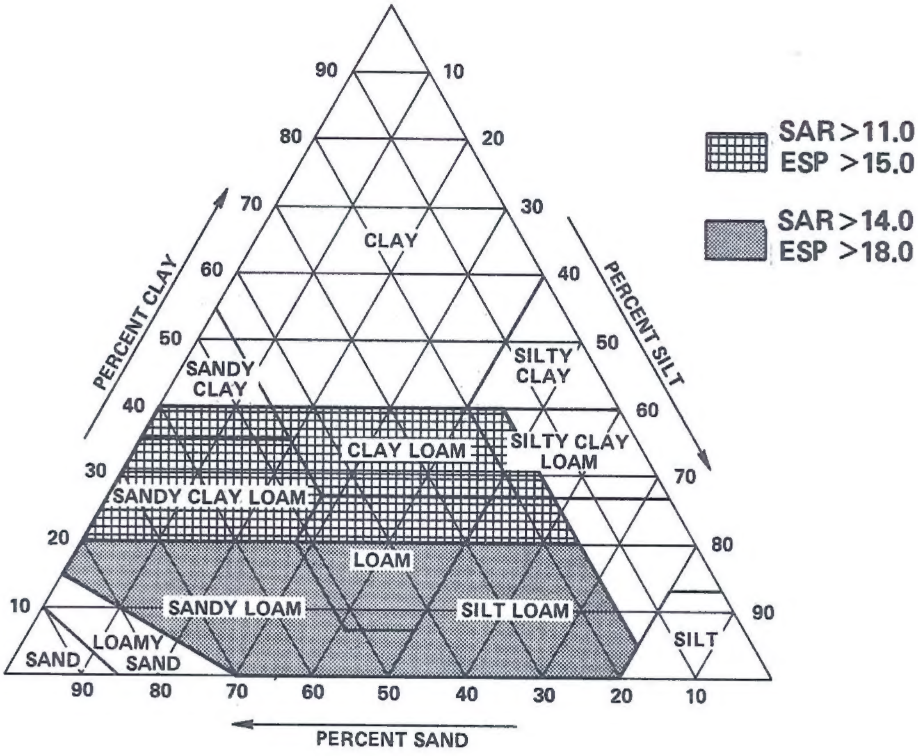
[1] See footnote 1 in Appendix A

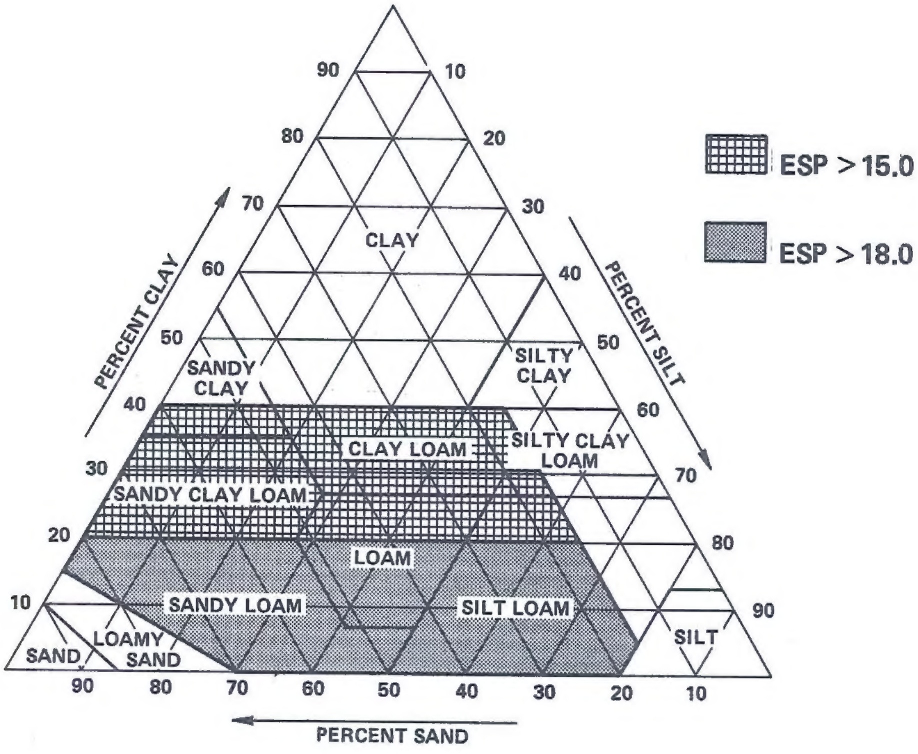
[2] See footnote 2 in Appendix A

[3] See Figure 2.

[4] The actual maximum acceptable molybdenum level will depend upon the plant species proposed in the revegetation plan and their potential for molybdenum accumulation.

TABLE 10. (Cont.)





Wyoming Draft Guidelines No. 1--Topsoil and Overburden

TABLE 11a. CRITERIA TO ESTABLISH SUITABILITY OF TOPSOIL (OR TOPSOIL SUBSTITUTES).

Parameter	Suitable	Marginal[1]	Unsuitable
pH	5.5 - 8.8	5.0 - 5.5 8.8 - 9.0	5.0 9.0
EC (Conductivity) mmhos/cm	0 - 8	8-16 may prove difficult to revegetate	16
Saturation Percentage	25 - 80	80 25	
Texture[2]	sl, l, sil, scl, vfsl, fsl	cl, sicl, sc, ls, lfs	c, sic, s
SAR	10	10 - 15 10 - 12[3]	15 12[3]
Selenium	2.0 ppm		2.0 ppm
Boron	5.0 ppm		5.0 ppm
Calcium Carbonate	0 - 30%		over 30%
2mm - 3 in	0 - 35	35 - 50	50
Coarse Frag 3-10 in	0 - 25	25 - 35	35
(% vol) 10 in	0 - 7	7 - 10	10
Moist Consistency vfr, fr	lo, fi	vfi, exfi vh	
Dry Consistency lo, so	sh, h		

Source: Ackerman 1983.

[1] Evaluated on an individual basis for suitability.
[2] SCS. 1978. National Soils Handbook, Notice 24.
[3] For fine-textured soils (Clay 40%) (Gee et al., 1978).

Wyoming Draft Guidelines No. 1--Topsoil and Overburden

TABLE 11b. CRITERIA TO ESTABLISH OVERBURDEN SUITABILTIY.

	Surface (potential root zone)		Aquifer Restoration	
Parameter	Suitable	Unsuitable	Suitable	Unsuitable
pH	5.0-9.0	5.0 9.0	5.0-9.0	5.0 9.0
EC (Conductivity) mmhos/cm	<8.0[1]	>8.0		Depends on premining water quality and overburden quality
Saturation Percentage	25-30	80 25		
Texture	50% clay 85% sand	50% clay 85% sand		
SAR	12 15	12[1] 15		Depends on premining water quality and overburden quality
Selenium	2.0 ppm	2.0 ppm		Depends on premining water quality and overburden quality
Boron	≤ 5.0 ppm[5]	≥ 5.0 ppm		Depends on premining water quality and overburden quality
Nitrate/ Nitrogen			50 ppm	50 ppm
Molybdenum	1.0 ppm	1.0 ppm		

TABLE 11b. (Cont.)

	Surface (potential root zone)		Aquifer Restoration	
Parameter	Suitable	Unsuitable	Suitable	Unsuitable
Copper[2]				
Lime	30%	30%[3]		
Acid-base Pot.[4]	-5 tons $CACO_3$ equivalent/1000 tons	-5 tons $CACO_3$ equivalent/1000 tons		5 tons $CACO_3$ equivalent/1000 tons
Lead	10 ppm	10 ppm		Depends on premining water quality and overburden quality
Arsenic	2.0 ppm	2.0 ppm		Depends on premining water quality and overburden quality
Organic Carbon		10%		

Source: Ackerman, 1983.

[1] Overburden material placed directly under respread topsoil should be of similar suitability as the topsoil. The upward migration of soluble salts must be considered. SAR critical level will be dependent on texture. 12 for 40% clay. 15 for 40% clay.

[2] An excessive consuption of molybdenum through ingestion of vegetation may be toxic to animals. The concern is directly related to the Cu:Mo ratio in the plant tissue.

[3] Determined by analysis of neutralization potential of acid-base potential.

[4] Record as Acid pot., Neutralization pot. and acid-base potential in ± tons $CaCO_3$ equivalent/1000 tons.

[5] Critical level will be 8.0 ppm B unless oxidizable sulfur content is greater than 0.5%.

TABLE 12. SOIL AND OVERBURDEN STUDIES AND GUIDELINES FOR NORTH DAKOTA

Topsoil		Subsoil		Toxic overburden	
pH	---	pH	---	EC	6 mmhos
EC	2 mmhos	EC	4 mmhos	SAR	12
SAR	4	SAR	10		
$CaCO_3$	10%	Texture	---		
Organic matter	1.5%				
Texture	---				

Safaya 1983

developed an extracting procedure based on ammonium bicarbonate--DTPA, which has been widely adopted by agricultural studies of microelements and surface mine regulatory authorities. The nature of the extractant and the procedure produce data which is comparable only with other information collected similarly. In times of limited research monies for the necessary greenhouse and field studies to properly interpret such analytical data, the restriction of the number of extracting procedures has great benefit.

An exception to the rejection of the total analysis by strong acids has been where attempts were being made to solve specific soil chemical questions unrelated to plant uptake. There is a role for such analysis in evaluating overburden materials for use within the plant root zone. Overburden, to a large part, has not been recently exposed to a weathering environment. Extracting solutions described above will only remove substances which can approximately be extracted by plant roots. There are biogeochemical changes which will take place in overburden materials which potentially could make available toxic microelements in sufficient quantities to reduce plant growth or be toxic to herbivores. Highly selective sampling of overburden materials restricted to lithologic units known to contain potentially toxic microelements for total analysis would provide data to evaluate the potential hazard.

Overburden samples being prepared for analysis pose a particular problem. As an example, the reclamation planner requires information about texture. Through rigorous grinding, the sample can be reduced to its primary particles, with even some attenuate reduction in those particles. However, in the field, such disintegration of overburden may take centuries to accomplish. Associated chemical changes are brought about by such sample preparation techniques since the reduction in particle size results in dramatically increased surface areas and resultant chemical activity. Sample preparation techniques have been standardized for soil materials, but large errors have been introduced into overburden analysis by the use of differing preparation techniques. Munshower et al. (1982) found significant differences in microelement composition from overburden samples ground to differing fineness. Soils are routinely passed through a 2-mm sieve as a step in the accepted sample preparation technique. When analyzing samples from skeletal soils or those having large components of indurated shale platelets, this procedure can result in highly biased analytical results.

Regulatory authorities and reclamation planners, either within the industry or from consulting firms, face a serious problem in evaluating the reliability of soil and overburden analytical data. Sandoval (1979) constructed three large soil samples and distributed them to four premiere soil-testing laboratories in the Western States and ten other laboratories from the region. The resulting data are found in Table 13. The magnitude of the differences suggests the need for immediate action by those trying to interpret such information. Harrington (1977), in the Montana Guidelines (see Appendix B), has suggested 10 percent duplicate sampling. Fisher (1977) extended Harrington's concept to include 10 percent duplicate sampling, simple numbering of the samples, submitting the duplicate samples to a different laboratory and assigning an acceptable error or difference in values received prior to instituting the testing program. Berg (1983), along with the Western Soil and Overburden

TABLE 13. COMPARATIVE LABORATORY DATA ON HOMOGENOUS SOIL SAMPLES PREPARED BY SANDOVAL, USDA-SEA, MANDAN, ND (1979).

	Calcium carbonate equivalent (eq)			Organic carbon percentage			Mechanical analysis clay content percentage		
	ARS-1	ARS-2	ARS-3	ARS-1	ARS-2	ARS-3	ARS-1	ARS-2	ARS-3
Lab A	2.8	1.1	8.4	1.2	1.8	4.6	43	32	37
Lab B	1.4		5.4						
Lab C	2.8	0.7	7.7	1.2	1.6	4.2			
Lab D	1.1		6.8				34	27	28
Lab E							36	26	27
Lab F	0.9	0.2	6.7				41	33	35
Lab G	3.0	1.9	4.9						
Lab H	0.2	0.1	0.6	1.2	1.8	3.5	23	35	30
Lab I	2.0	0.5	7.8	1.0	1.7	2.9	40	30	34
Lab J	4.8	2.3	2.8	0.9	1.7	3.2	36	25	29
Lab K	1.4	0.4	7.7	1.9	3.3	4.6	44	53	47
Lab L							43	29	33
Lab M	2.8	0.9	8.1	1.2	1.7	4.4	36	24	31
Lab N	3.3	8.1	1.6				43	31	35
n	12	10	12	7	7	7	11	11	11
$\bar{x}$ of n	2.2	1.6	5.7	1.2	1.9	3.9	38.1	31.4	33.3
Range	0.2-4.8	0.1-8.1	0.6-8.4	0.9-1.9	1.6-3.3	2.9-4.6	23-44	25-53	27-37
Std. Dev.	1.3	2.4	2.7	0.3	0.6	0.7	6.1	8.0	5.6

Methods by U.S. Salinity Laboratory (USDA Handbook No. 60, 1954) and SEA (USDA Handbook No. 525, 1978).

Four laboratories were identified:
- (A) USDA-SEA-AR of Mandan, ND
- (B) Riverside, CA
- (C) Colorado State University, Fort Collins, CO
- (D) North Dakota State University, Fargo, ND
- (E-N) Unidentified laboratories.

TABLE 13. (Cont.)

	Saturation percentage			Electrical conductivity mmhos/cm			Cation exchange capacity meq/1 0 gm soil			Exchangeable sodium percentage		
	ARS-1	ARS-2	ARS-3	ARS-1	ARS-2	ARS-3	ARS-1	ARS-2	ARS-3	ARS-1	ARS-2	ARS-3
Lab A	68	45	85	5.2	0.8	7.9	27.6	21.4	39.1	13.5	5.0	11.8
Lab B	60	40	71	5.2	0.9	7.8	30.9	25.8	39.6	12.0	3.2	13.0
Lab C	56	45	66	5.0	0.8	7.5	27.3	19.3	33.3	13.6	4.2	16.5
Lab D	52	35	64	5.6	0.9	8.0	32.3	26.0	16.1	12.1	3.4	41.6
Lab E	65	46	83	5.3	6.4	8.1	25.0	20.8	14.0	12.5	3.7	25.4
Lab F	64	55	65	6.0	1.3	8.7	22.3	19.5	35.4	27.5	6.6	23.1
Lab G	46	30	50	6.6	1.2	9.3	22.2	18.5	30.4	50.4	14.6	69.5
Lab H	65	72	60	4.9	1.2	8.4	11.0	22.5	12.5	63.7	3.8	78.7
Lab I	50	37	63	3.8	0.6	6.2	27.7	20.5	41.2	16.5	4.7	17.5
Lab J	62	41	80	5.3	0.9	7.9	37.2	32.9	53.0	12.5	2.9	13.9
Lab K	64	50	75	4.4	0.8	5.7	30.0	30.0	40.0	10.0	2.6	8.0
Lab L	59	42	73	5.4	0.9	7.0						
Lab M	65	43	82	4.3	0.8	6.0						
Lab N				5.0	0.8	7.6						
n	13	13	13	14	14	14	11	11	11	11	11	11
x of n	59.7	44.7	70.5	5.1	1.3	7.6	26.7	23.4	32.2	22.2	5.0	29.0
S. Dev.	6.8	10.4	10.4	0.7	1.5	1.0	6.8	4.7	12.9	18.0	3.4	21.1
Range	46-68	30-72	50-82	4,3-6.6	0.6-6.4	6.0-9.3	11-37	19-33	12-53	10-27	3-15	8-79

Methods by U.S. Salinity Laboratory (USDA Handbook No. 60, 1954) and SEA (USDA Handbook No. 525 1978).

Four laboratories were identified:
(A) USDA-SEA-AR of Mandan, ND
(B) Riverside, CA
(C) Colorado State University, Fort Collins, CO
(D) North Dakota State University, Fargo, ND
(E-N) Unidentified laboratories.

Study Group, have begun developing a round-robin system providing participating laboratories with standardized samples. The precise mechanics of the system have not been finalized, but the program represents a significant step in correcting some of these errors.

Three problems currently dominate the soil and overburden data acquisition for coal leasing and mine plan development. The problems related to interpretating analytical data to determine suitability for topsoil or subsoil have already been mentioned and certainly plague both industry and regulators. Two problems occurring in earlier stages of the studies, to some extent, override the problems with interpretation--first, the errors associated with making the field soil survey are often very large, and second, the problems associated with analytical work necessary to develop the basic soil and overburden data.

Inaccuracies associated with preparing soil surveys is a complex and multifaceted problem. Errors or mistakes are made both in placing lines on the aerial photograph or base map and in identifying the components of the mapping unit. To those familiar with the soil survey effort, these errors are of real concern but often they are not the primary cause of mistakes made in applying soil survey information. In recent years, there has been a strong tendency for survey administrators to want to restrict the number of mapping units and series recognized in large counties, such as Campbell County, Wyoming (with more than four million acres). This method simply forces the field surveyor to develop complex mapping units without careful and restricted definition of the percentages of the primary soil series included in each mapping unit. In the case where large numbers of mapping units have been recognized, these are frequently combined during correlation prior to publication of the survey report, resulting in further generalization of the inventory. A similar tendency to reduce or restrict the number of soil series recognized in a survey pervades many soil surveys. An even more important factor in the loss in detail or site-specific reliability has been the high levels of production being required from field personnel. It is not possible to produce highly reliable inventories of four sections (2,560 acres) in a single day. Such mapping serves an important need--but it is of a reconnaissance-type of detail and cannot be used for evaluating land for surface mining or conservation planning of cropland.

One of the primary problems facing those who would like to increase the reliability of soil survey and/or prevent some of the errors in applying such information is that of developing an understanding among survey users of the relationship between intensity of survey and potential for use. Tables 14 and 15 are included to suggest some of the potential that a user can make of specific types of soil inventories. By applying this information to the leasing and mine planning efforts, some of the problems currently being experienced can be put into perspective. The use of Order 2 or 3 soil surveys for evaluating reclaimability of a site without supplementary field and laboratory data simply means that the individual or agency is willing to accept major errors in the soil data which must be included in the leasing decision. Several states still use Order 2 soil surveys (frequently not much better or more detailed than Order 3 surveys) for the planning of mines and reclamation/revegetation efforts. Such efforts are supported by analytical

TABLE 14. SOME MINIMUM MAP SCALE AND OBSERVATION REQUIREMENTS FOR LAND CLASSIFICATION AS USED BY THE U.S. BUREAU OF RECLAMATION IN DETERMINING IRRIGATED LAND SUITABILITY

Specification	Reconnaissance map	Semi-detailed map	Detailed map
Scale of base maps	1:24,000	1:12,000	1:4,800
Land classes recognized	1,2,3,6	1,2,3,6	1,2,3,4,5,6
Maximum distances between traverses (miles)	1.00	0.50	0.25
Accuracy (percent)	75	90	97
Field progress per day for one land classifier and crew (square miles)	3.00-5.00	1.00-3.00	0.25-1.00
Minimum soil borings of pits per square mile (5 ft deep)	1	4	16
Minimum number of deep sub-strata holes per township (10 ft deep or more)	1	2	4

Source: U.S. Bureau of Reclamation 1953.

TABLE 15. RELATIONSHIPS OF SOIL INVENTORY INTENSITY AND LEVEL OF INTENSITY AT WHICH MAP UNIT DELINEATIONS ARE RECOGNIZED AND SOILS ARE CLASSIFIED.

	Order 1	**Order 2**	**Order 3**	**Order 4**	**Order 5**
Taxonomic classification	series	series	families and series	families and subgroups	subgroups, great groups, suborders, and orders
Map unit	phases of soil series	phases of soil series	phases of soil series and soil families	associations with some consociations	associations
Map scale needed	1:12,000 and larger	1:12,000 to 1:31,680	1:24,000 to 1:250,000	1:100,000 to 1:300,000	1:250,000 to 1:1,000,000
Smallest unit mapped	less than 1.5 acres	1.5-10 acres	6-640 acres	100-1,000 acres	640-10,000 acres
Percent dissimilar inclusions	less than 10 percent	less than 20 percent	less than 30 percent	not set in advance	not set in advance
Accepted uses	experimental plots and individual home sites ... the nearest survey intensity to being site specific	planning of moderately intensively used management units, based on predictions of the suitabilities and soils response to management	planning for extensive uses of land such as rangeland, watershed management, woodland, and extensive kinds of cropland...county, multicounty, or watershed planning	regional planning within multicounty or multistate areas or larger watersheds ... used to locate areas having potential for 2nd order survey and for site management planning	used for broadest kinds of planning for states or nations ... accurate identification of most important soils and reasonable estimates of their extent
Field methods	Identification of soils of each delineation by direct examination of all boundaries throughout their lengths. Sampling plan of grid applied at random, in addition to soil examinations at places dictated by surface features that may mark soil differences. Laboratory determinations on samples collected at selected places to verify or augment field observations.	Identification of soils by transecting and transversing. Soil boundaries are plotted by observation and interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals.	Soils in each delineation are identified by transecting and transversing and some observation. Boundaries are plotted by observation and interpretation by remotely sensed data and verified with some observations.	The soils of delineation representative of each map unit are identified and their patterns and composition determined by transecting. Subsequent delineations are mapped by transversing, by some observation, and by interpretation of remotely sensed data verified by occasional observations. Boundaries are plotted by air photo interpretations.	The soils, their patterns, and their composition for each map unit are identified through mapping selected areas (15 to 25 mi^2) with 1st or 2nd order surveys, or alternatively, by transecting. Subsequently, mapping is by widely spaced observations, or by interpretation of remotely sensed data with occasional verification by observation or transversing.

Source: Barrett 1980.

work but this is of little help to the reclamation planner if the lines are not drawn properly or the soils included within the delineation are not properly described. The analytical work is of value only if it reflects the soil series or type found within the mapping delineation.

The comments above should not be interpreted to suggest that soil surveys are either not worth preparing or using in making resource decisions. On the contrary, far too many decisions are being made today either without appropriate soil resource input or the decision is a foregone conclusion and evaluating resource data is not taken seriously. Many land management agencies and corporations are very hostile to questions about the reliability of resource inventory information upon which land use decisions are being made. Agencies and consulting firms supporting or preparing soil surveys are not inclined to take a serious look at the quality or limitations of the product. The crux of the problem is that we must define the limits of reliability of the inventory and use them in the evaluation and application of the inventory product.

SOIL QUALITY

Fundamental to all reclamation activities is the establishment of postmine land use objectives and specific cirteria and techniques for measurement of success in meeting those goals. The minesoils constructed in the reclamation effort must meet or exceed the requirements of the land use described in the planning process. In the West, the current trend is to return the land to a grass-dominated system with the primary objective being the production of forage for livestock. North Dakota and Colorado differ slightly in planning to return significant amounts of lands to small-grain production, which in some instances is mandated through regulations for reclamation of prime farmlands. Integrating several edaphic factors will be necessary to achieve the production requirements stipulated in the performance standards. Paramount among these soil factors relating to enhancement of soil quality are increases/maintenance of available water holding capacities, soil organic matter, soil depth* as related to rooting depth, soil structure, slopes and minesoil characteristics which will have very limited runoff which could potentially result in sheet or rill erosion.

A major problem has developed in establishing some shrubs and tree species in the West. Part of this problem is traceable to the lack of understanding of the techniques required for establishing the species and the biological nature of the plant material being used in the revegetation effort. Competition between the young grass and shrub seedlings for surface moisture has resulted in major losses in shurbs when seeded. Being able to consistently place seed at the appropriate depth has been a limiting factor in establishing some shrub species. Stark (1982) has demonstrated the ecotypic variation within ponderosa pine (*Pinus ponderosa*).

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*All minesoils are deep by definition since there is no underlying indurated bedrock or paralithic material after mining has taken place.

Aside from the problems mentioned above, one of the most important reasons for the lack of success in revegetating with shrubs is the lack of understanding of their site requirements and using available information. Reclamation planning will have to start to make more sophisticated use and interpretation of soil and vegetation baseline data to construct minesoils that meet the requirements of shrub species (see Fig. 22). The ponderosa pine naturally growing in or near a fractured sandstone bedrock system (from which it draws moisture concentrated in the fracture planes) will have great difficulty in competing on a minesoil which has a relatively homogenous character. The moisture relationships in those two sites or soils are very different.

Current reclamation efforts apparently will, in most instances, meet the bond release revegetation requirements for biomass production and vegetation cover. To date, regulatory authorities have not adopted sound scientifically based methods of measuring revegetation success. One of the key factors will have to be establishing the permissible levels of technological inputs--fertilizers, herbicides, pesticides, irrigation--that are allowable in the comparison between the reclaimed area (minesoil) and the reference area. Salvaging of topsoil with higher organic matter and hence fertility levels can be substituted for by using commercial fertilizer but only on a temporary basis.

MITIGATING SURFACE MINE IMPACTS ON SOILS

Several advances in mitigating impacts on the soil resource have been made recently in Western reclamation. The double lifting of the soil resource--the first lift removing the topsoil composed primarily of the A and upper portions of the B horizon and the second lift removing the subsoil which contains the B and at times the C horizon. Modifying the double lift to alter the composition of the first lift to include the B horizon if the clay content were below 35 percent and which was decalcified has been adopted. The second lift then would include the heavier textured B horizons, cambic types of B horizons which were not decalcified, and C materials. The special handling procedures required for prime farmland soils will almost certainly have to be extended into rangeland areas where shrub-dominant plant communities are to be established. The double lift type of soil removal is now widely practiced in this region. The double lift system is an extremely valuable tool, but the success of the reclamation effort in most areas depends to a large extent upon careful selection and replacement of soil materials best suited to plant growth.

Direct hauling of topsoil from an area being developed for mining to a site which has been graded to a site and where the subsoil has been replaced is a very successful method of revegetating shrubs and other native species. Many plant propagules are carried along with the topsoil and serve to revegetate the area being reclaimed. Data is very limited but almost certainly there are important mycorrhizal associations with several of the shrub and tree species in this region (Stark 1982). Microbiological organisms which are of great importance in nutrient cycling, litter decomposition and nitrogen fixation can be preserved by directly haulting topsoil materials. Realistically, topsoils stored for more than a year are only slightly better than the better quality

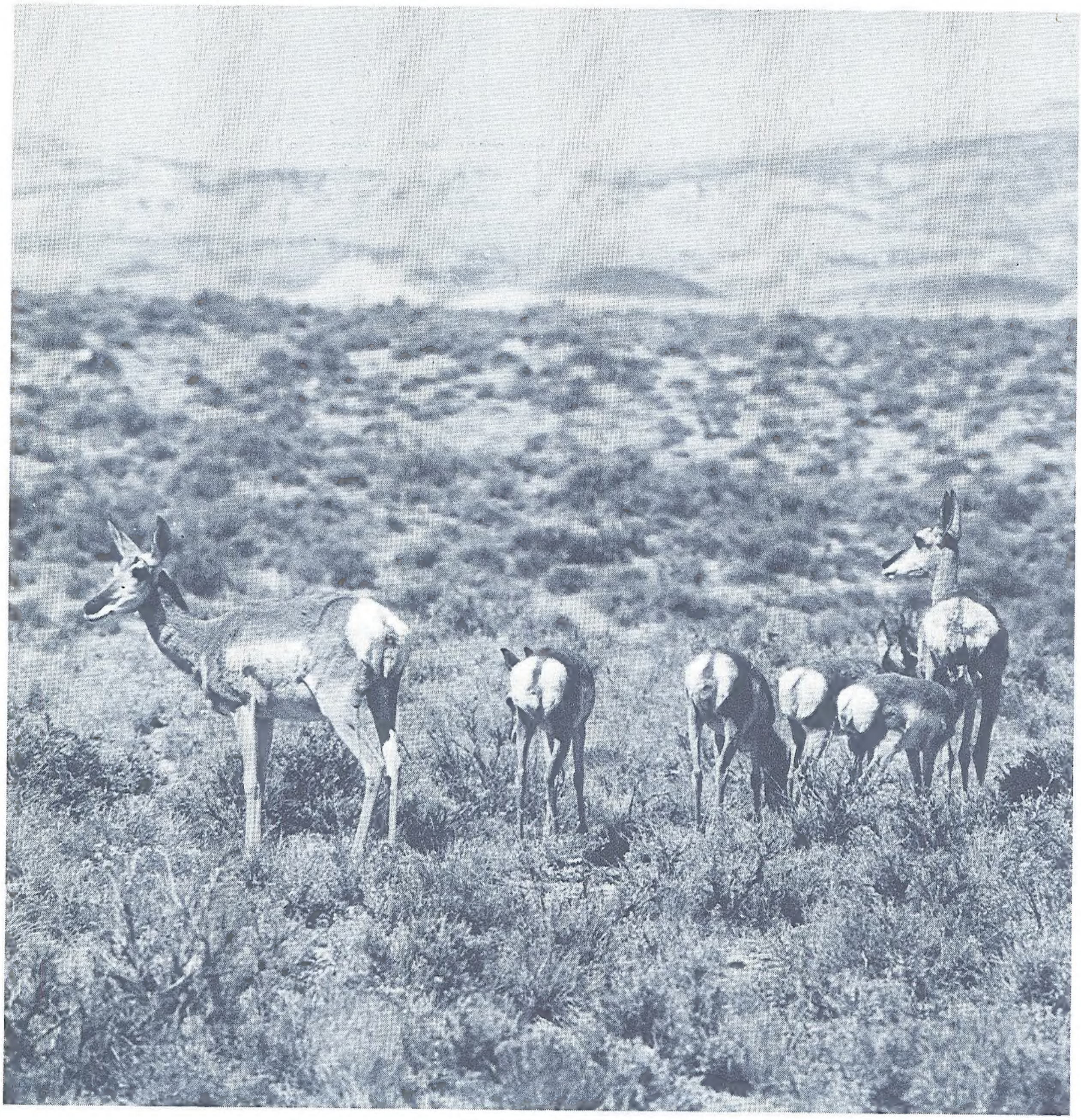

Figure 22. Antelope require shrub-dominated ecosystems, particularly during critical winter months. Highly sophisticated reclamation planning, soil handling and revegetation efforts are required to replace such plant communities. Current reclamation in the region is producing grass-dominated plant communities. Antelope are an important economic resource to Wyoming's economy, coming from both hunters and tourists (photo--Wyoming Game and Fish Department).

overburden substances. Unfortunately, most of the work with direct hauling of topsoil remains undocumented. A serious need exists to compare direct hauling with topsoil storage for a variety of soils and climatic regimes.

Special handling of both soil and overburden materials will become routine in the future, particularly when the postmine land use is for cropland, dominantly small grains in this region, or establishing of many shrub/tree species. Under the current reclamation procedures, mixing all topsoil materials and all subsoil materials from an area will generally produce satisfactory revegetation, given the grass-dominated plant communities and the long, uniform planar slopes in today's reclaimed landscape. The diversity of plant communities on such an area is limited due primarily to the uniformity in the minesoils. Schafer (1979) concluded that minesoils were less variable on a landscape scale (>500-m spacing) than the natural soils in southeastern Montana. Munshower (1982) emphasized the need for providing diversity in the minesoils occupying the reclaimed landscape to support a diverse range of plant communities.

The use of carefully selected overburden materials to augment the amount of soil available for minesoil construction will become more routine in the future. Many of the existing and proposed mines in the Powder River, Green River-Hams Fork and Fort Union coal regions do not have sufficiently high quality soil resources to support the diversity in revegetated plant communities being sought after. To obtain similar production values to premine soils or reference areas, the rooting medium will have to be deep--as much as 6' to 10' in some cases. Schuman (1978) concluded that mixing subsoil and suitable mine spoil materials could be used to increase the soil material amount without detrimental effects. The overburden mixing procedure would be particularly beneficial in the case where only poor quality soil resources were available and the overburden materials were well adapted to this use. The use of boulder-sized particles from the overburden will be required when reestablishing some plant species--Ponderosa pine, as an example, and when reconstructed mine landscapes have steep slopes needing physical stabilization by such materials.

The capability classification of the existing soil resource can be utilized as one factor in evaluating the soil mitigation procedures in the reclamation plan. Unfortunately, neither the capability classification nor the basic characteristics of the reclaimed soil has been defined in most mine plans. In the inclusion of land capability classification, data can be utilized to assess the risks that are being taken by allowing the proposed action to take place. The potential exists to design a reclamation program with sufficient detail that the capability of the components of the postmine landscape could be defined. Secondly, the existing regulations do not specify returning minesoils to a capability; or potential equal to or better than the premine soil. Certainly more emphasis on the quality of the minesoil would result in enhanced production from the revegetation effort and further limitation of the offsite impacts from the development.

APPENDIX A. SOIL DESCRIPTIONS AND INTERPRETATIVE DATA.

APPENDIX A.1. ARNEGARD SERIES.

Established Series
Rev. FWW-GBM
11/16/78

ARNEGARD SERIES

The Arnegard series consists of deep, well drained soils that formed in calcareous loamy alluvium on upland swales, fans and footslopes. Permeability is moderate. Slopes range from 0 to 9 percent. Mean annual temperature is 42° F, and mean annual precipitation is 14 inches.

Taxonomic Class: Fine-loamy, mixed Pachic Haploborolls.

Typical Pedon: Arnegard loam - cultivated. (Colors are for dry soil unless otherwise stated.)

Ap--0 to 11 inches; dark grayish brown (10YR 4/2) loam, very dark brown (10YR 2/2) moist; weak coarse and medium subangular blocky structure parting to weak fine granular; very friable; many roots; neutral; clear wavy boundary. (8 to 18 inches thick)

B21--11 to 17 inches; dark grayish brown (10YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; weak coarse and medium prismatic structure parting to moderate fine subangular blocky; few thin clay films on faces of peds; common roots; common pores; neutral; gradual wavy boundary.

B22--17 to 25 inches; grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 3/2) moist; moderate medium prismatic structure parting to moderate medium and fine angular blocky; friable; few thin clay films on faces of peds; few roots; common pores; neutral; clear wavy boundary. (Combined thickness of the B2 horizon is 8 to 30 inches.)

B3--25 to 32 inches; grayish brown (2.5Y 5/2) loam, very dark grayish brown (2.5Y 3/2) moist; weak coarse prismatic structure parting to weak coarse and medium subangular blocky; friable; neutral; clear wavy boundary. (0 to 10 inches thick)

C1ca--32 to 45 inches; light brownish gray (2.5Y 6/2) loam, dark grayish brown (2.5Y 4/2) moist; weak coarse and medium subangular blocky structure; friable; few roots; few fine pores; soft bodies of segregated lime; strong effervescence; moderately alkaline; gradual wavy boundary. (7 to 16 inches thick)

C2--45 to 60 inches; light yellowish brown (2.5Y 6/4) loam, light olive brown (2.5Y 5/4) moist; very weak coarse and medium subangular blocky structure; friable; strong effervescence; moderately alkaline.

Type Location: McKenzie County, North Dakota; 300 feet east of the NW corner of sec. 14, T. 150 N., R. 101 W.

Range in Characteristics: The solum thickness ranges from 20 to 58 inches. The mollic epipedon ranges from 16 to more than 30 inches in thickness and includes all or part of the B horizon. The soil typically has segregated or finely divided carbonates within depths of 40 inches but ranges to as deep as 60 inches.

The A horizon has hue of 10YR, value of 3 or 4 and 2 or 3 moist, and chroma of 2. It is loam or silt loam and is slightly acid or neutral. Some pedons have B1 horizons.

The B2 horizon has hue of 10YR or 2.5Y, value of 2 to 4 moist, and chroma of 2 or 3. It is loam, silt loam or light clay loam containing less than 30 percent clay. It is neutral or mildly alkaline.

The Cca horizon has hue of 2.5Y or 10YR, value of 5 to 7 dry and 4 or 5 moist, and chroma of 2 to 4. It is typically loam but includes fine sandy loam to clay loam. It is mildly or moderately alkaline.

The C horizon has hue of 2.5Y or 10YR, value of 5 to 7 dry and 4 or 5 moist, and chroma of 2 to 4. It typically is loam but includes loamy fine sand, fine sandy loam and clay loam. It is neutral to moderately alkaline.

ARNEGARD SERIES--2

Competing Series: These are the Falkirk, Garza, Roseglen and Shawa series in the same family and the Bowbells, Bowdle, Goshen, Grail, Grassna, Mandan, Onita, Parshall, Shambo, Straw and Svea series. Falkirk soils have gravelly loam IIC horizons and glacial till within depths of 40 inches. Garza soils lack cambic horizons. Roseglen soils contain less sand and have formed in lacustrine sediments. Shawa soils lack B horizons and formed in alluvium primarily from igneous rocks. Bowbells soils have argillic horizons. Bowdle soils are fine-loamy over sandy or sandy-skeletal. Goshen and Onita soils have argillic horizons and warmer climates. Grail soils have fine-textured argillic horizons. Grassna soils are fine-silty. Mandan soils are coarse-silty. Parshall soils are coarse-loamy. Shambo soils have mollic epipedons less than 16 inches thick. Straw soils contain carbonates throughout and are stratified. Svea soils have wetter climates.

Geographic Setting: Arnegard soils are on upland swales, fans and footslopes on the residual plains and glacial till plains. They formed in mixed loamy alluvium from calcareous sedimentary rock and glacial till. Slopes typically are 1 or 2 percent but range from 0 to 9 percent. The mean annual temperature is 38 to 45° F, and the mean annual precipitation is 12 to 16 inches, most of which falls during spring and summer.

Geographically Associated Soils: These are the Amor, Farland, Grail, Grassna, Max, Morton, Parshall, Sen, Shambo, Temvik, Vebar and Williams soils. Amor, Morton, Sen and Vebar soils have thinner mollic epipedons formed in residual materials and are on nearby convex slopes. Farland and Shambo soils have thinner mollic epipedons and are on nearby terraces. Max, Williams and Temvik soils have thinner mollic epipedons and formed in glacial till. Grail, Grassna and Parshall soils are in similiar positions.

Drainage and Permeability: Well drained. Runoff is slow or medium. Permeability is moderate.

Use and Vegetation: Most areas are cropped to spring wheat, oats, barley, and hay. Native vegetation is mid, tall and short grasses such as western wheatgrass, green needlegrass, big bluestem and blue grama.

Distribution and Extent: Arnegard soils are extensive and are in western North Dakota, eastern Montana and northwestern South Dakota.

Series Established: McKenzie County, North Dakota, 1937.

Remarks: Soils that formed in loess or similiar silty materials were formerly included in the Arnegard series but now are placed in the Grassna series.

National Cooperative Soil Survey
U.S.A.

APPENDIX A.1. (Cont.)

NC0051

SOIL INTERPRETATIONS RECORD

ARNEGARD SERIES

MLRA(S): 53, 54
REV. OCT. 10-78
PACHIC HAPLOBOROLLS, FINE-LOAMY, MIXED

THE ARNEGARD SERIES CONSISTS OF DEEP.WELL DRAINED SOILS FORMED IN LOAMY ALLUVIUM IN UPLAND SWALES.FANS AND FOOTSLOPES. THE SURFACE LAYER IS DARK GRAYISH LOAM 11 INCHES THICK. THE SUBSOIL IS DARK GRAYISH BROWN AND GRAYISH LOAM 21 INCHES THICK. THE UNDERLYING MATERIAL IS LIGHT BROWNISH GRAY AND LIGHT YELLOWISH BROWN LOAM. SLOPES RANGE FROM 0 TO 9%. SOILS ARE CULTIVATED OR GRAZED.

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-11	L. SIL	CL-ML. CL	A-4. A-6	0	100	100	85-100	60-90	20-35	5-20
11-32	L. SIL. CL	CL	A-6	0	100	100	85-100	50-90	25-40	12-25
32-60	L. CL. LFS	SM. ML. CL. SC	A-4. A-6	0	100	100	70-100	40-80	15-40	NP-15

DEPTH (IN.)	CLAY (PCT <2MM)	MOIST BULK DENSITY (G/CM3)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND EROD. GROUP	ORGANIC MATTER (PCT)	CORROSIVITY STEEL	CONCRETE
0-11	15-25	1.00-1.40	0.6-2.0	0.20-0.24	6.1-7.3	<2	MODERATE	.28	5	6	3-6	HIGH	LOW
11-32	18-30	1.20-1.60	0.6-2.0	0.16-0.22	6.6-7.8	<2	MODERATE	.28					
32-60	5-30	1.20-1.60	0.6-2.0	0.14-0.18	6.6-8.4	<2	LOW	.28					

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			-		>60		-		B	MODERATE

SANITARY FACILITIES

SEPTIC TANK ABSORPTION FIELDS	0-8%: MODERATE-PERCS SLOWLY 8-9%: MODERATE-PERCS SLOWLY.SLOPE
SEWAGE LAGOON AREAS	0-2%: MODERATE-SEEPAGE 2-7%: MODERATE-SEEPAGE.SLOPE 7+%: SEVERE-SLOPE
SANITARY LANDFILL (TRENCH)	0-8%: MODERATE-TOO CLAYEY.TOO SANDY 8-9%: MODERATE-SLOPE.TOO CLAYEY.TOO SANDY
SANITARY LANDFILL (AREA)	0-8%: SLIGHT 8-9%: MODERATE-SLOPE
DAILY COVER FOR LANDFILL	0-8%: FAIR-TOO CLAYEY.TOO SANDY 8-9%: FAIR-TOO CLAYEY.TOO SANDY.SLOPE

BUILDING SITE DEVELOPMENT

SHALLOW EXCAVATIONS	SEVERE-CUTBANKS CAVE
DWELLINGS WITHOUT BASEMENTS	0-8%: MODERATE-SHRINK-SWELL 8-9%: MODERATE-SHRINK-SWELL.SLOPE
DWELLINGS WITH BASEMENTS	0-8%: SLIGHT 8-9%: MODERATE-SLOPE
SMALL COMMERCIAL BUILDINGS	0-4%: MODERATE-SHRINK-SWELL 4-8%: MODERATE-SHRINK-SWELL.SLOPE 8+%: SEVERE-SLOPE
LOCAL ROADS AND STREETS	SEVERE-LOW STRENGTH
LAWNS. LANDSCAPING AND GOLF FAIRWAYS	0-8%: SLIGHT 8-9%: MODERATE-SLOPE

CONSTRUCTION MATERIAL

ROADFILL	GOOD
SAND	IMPROBABLE-EXCESS FINES
GRAVEL	IMPROBABLE-EXCESS FINES
TOPSOIL	0-8%: GOOD 8-9%: FAIR-SLOPE

WATER MANAGEMENT

POND RESERVOIR AREA	0-3%: MODERATE-SEEPAGE 3-8%: MODERATE-SEEPAGE.SLOPE 8+%: SEVERE-SLOPE
EMBANKMENTS DIKES AND LEVEES	SEVERE-PIPING
EXCAVATED PONDS AQUIFER FED	SEVERE-NO WATER
DRAINAGE	DEEP TO WATER
IRRIGATION	0-3%: FAVORABLE 3+%: SLOPE
TERRACES AND DIVERSIONS	0-8%: FAVORABLE 8+%: SLOPE
GRASSED WATERWAYS	0-8%: FAVORABLE 8+%: SLOPE

REGIONAL INTERPRETATIONS

APPENDIX A.1. (Cont.)

ARNEGARD SERIES NC0051

RECREATIONAL DEVELOPMENT

CAMP AREAS	0-8%: SLIGHT 8-9%: MODERATE-SLOPE	PLAYGROUNDS	0-2%: SLIGHT 2-6%: MODERATE-SLOPE 6+%: SEVERE-SLOPE
PICNIC AREAS	0-8%: SLIGHT 8-9%: MODERATE-SLOPE	PATHS AND TRAILS	SLIGHT

CAPABILITY AND YIELDS PER ACRE OF CROPS AND PASTURE (HIGH LEVEL MANAGEMENT) (A)

CLASS-DETERMINING PHASE	CAPABILITY		WHEAT, SPRING (BU)		OATS (BU)		BARLEY (BU)		GRASS-LEGUME HAY (TONS)							
	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
0-3%	2C		34		68		58		2.5							
3-6%	2E		31		62		53		2.3							
6-9%	3E		26		52		44		1.9							

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	MANAGEMENT PROBLEMS: EROSION HAZARD	EQUIP. LIMIT	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	POTENTIAL PRODUCTIVITY: COMMON TREES	SITE INDX	TREES TO PLANT
							NONE		

WINDBREAKS (B)

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
ALL	PLAINS COTTONWOOD	38	GOLDEN WILLOW	25	SIBERIAN CRABAPPLE	15	GREEN ASH	21
	PONDEROSA PINE	20	BLACK HILLS SPRUCE	20	COMMON CHOKECHERRY	14	EASTERN REDCEDAR	12
	PEKING COTONEASTER	8	SIBERIAN PEASHRUB	9	TATARIAN HONEYSUCKLE	8	AMERICAN PLUM	8

WILDLIFE HABITAT SUITABILITY

CLASS-DETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS: GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	POTENTIAL AS HABITAT FOR: OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
0-3%	GOOD	GOOD	GOOD	-	-	GOOD	POOR	V. POOR	GOOD	-	V. POOR	GOOD
3-6%	GOOD	GOOD	GOOD	-	-	FAIR	POOR	V. POOR	GOOD	-	V. POOR	FAIR
6+%	FAIR	GOOD	FAIR	-	-	FAIR	POOR	V. POOR	FAIR	-	V. POOR	FAIR

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION) (C)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE: 0-3%	3-9%			
BIG BLUESTEM	ANGE	20	-			
GREEN NEEDLEGRASS	STVI4	15	10			
WESTERN WHEATGRASS	AGSM	20	25			
NEEDLEANDTHREAD	STCO4	7	15			
BLUE GRAMA	BOGR2	5	13			
KENTUCKY BLUEGRASS	POPR	5	5			
OTHER PERENNIAL GRASSES	PPGG	10	12			
OTHER PERENNIAL FORBS	PPFF	8	10			
OTHER PERENNIAL GRASSLIKES	PPGL	5	5			
OTHER SHRUBS	SSSS	5	5			
POTENTIAL PRODUCTION (LBS./AC. DRY WT):						
FAVORABLE YEARS		3200	2550			
NORMAL YEARS		2800	2150			
UNFAVORABLE YEARS		2400	1750			

FOOTNOTES

A PREDICTED YIELDS GIVEN FOR LRA 53

B WINDBREAK GROUP 1.

C RANGE SITES:OVERFLOW FROM 0-3%; SILTY FOR 3-9%; COMPOSITION AND PRODUCTION IS FOR LRA 54. N. DAKOTA.

APPENDIX A.2. DILTS SERIES.

Established Series
Rev. AFB-DDO
6/11/73

DILTS SERIES

The Dilts series is a member of the clayey, montmorillonitic, acid, frigid, shallow family of Ustic Torriorthents. Typically these soils have olive gray clay A1 horizons about 5 inches thick and gray shaly clay C horizons underlain by platy claystone at depths of about 19 inches. Soils are acid throughout.

Typifying Pedon: Dilts clay - native grassland
(Colors are for dry soil unless otherwise stated.)

A1 — 0-5"--Olive gray (5Y 5/2) clay, olive gray (5Y 4/2) moist; weak medium subangular blocky and moderate fine granular structure; very hard, firm, sticky and very plastic; common fine roots; few small shale chips; medium acid; clear wavy boundry. (3 to 6 inches thick)

C1 — 5-19"—Gray (5Y 6/1) shaly clay, dark gray (5Y 4/1) moist; weak coarse subangular blocky parting to moderate medium and fine platy structure; extremely hard, very firm, sticky and very plastic; few roots; 25 to 75 percent by volume partly weathered claystone; strongly acid; gradual boundary. (8 to 14 inches thick)

C2 — 19-40"—Gray (5Y 6/1) platy claystone, clay when crushed; common yellow stains on plate surfaces; very strongly acid.

Type Location: Bowman County, North Dakota; 1455 feet east and 1420 feet north of west quarter corner Sec. 20, T. 130 N., R. 106 W.

Range in Characteristics: The depth to claystone or shale is less than 20 inches. The control section is clay or silty clay average 50 percent clay. The upper 24 inches of the soil is frozen for more than 100 days in most years. The A horizon has hue of 5Y or 2.5Y, value of 4 to 6 dry, 3 to 5 moist, and chroma of 1 or 2. It is clay or silty clay and has moderate or strong granular structure. It ranges from neutral to medium acid. The C horizon has hue of 5Y or 2.5Y values of 4 to 6 dry, 4 to 5 moist, and chroma of 1 to 3. It has weak to moderate blocky to weak to moderate platy structure and is medium or strongly acid. The shales and clays have few to many yellow and yellowish brown stains on the surface of the plates and along vertical cracks. The bedrock ranges from medium to very strongly acid. It contains 25 to 75 percent by volume of partly weathered claystone or shale.

Competing Series and Their Differentiae: There are no other series in the family. The Blackhall, Cabba, Cabbart, Chipeta, Epsie, Espy, Grummit, Lisam, Lismas, Louviers, Midway, Norbert, Samsil, Wayden and Yawdim series are similar. Blackhall and Cabbart soils are loamy. Cabba soils are usually moist and are loamy. Chipeta, Epsie, Lismas, Midway and Samsil soils have mesic soil temperatures. Louviers soils are usually moist and have mesic soil temperatures. Grummit soils have mesic temperatures and are strongly acid. The Espy, Lisam, and Yawdim soils are neutral or moderately alkaline, and the Yawdim soils contain less than 50 percent clay. Norbert and Wayden soils are usually moist and are not acid.

Setting: The Dilts soils are on undulating, rolling, and steep sedimentary plains. The Dilts soils formed in clay residuum weathered from claystone, mudstone, or shale. The climate is cool, semiarid with a mean annual temperature of 40 to 45°F.; and mean annual precipitation of 12 to 16 inches. Two-thirds of the precipitation falls in the spring and summer.

Principal Associated Soils: These are the competing Lisam and Yawdim soils and shale outcrops.

Drainage and Permeability: Excessively drained. Slow or very slow permeability; medium or rapid runoff.

Use and Vegetation: Used for rangeland. Native vegetation consists of thickspike wheatgrass, western wheatgrass, a few cedars and sagebrush in places.

Distribution and Extent: Southwestern North Dakota, southeastern Montana. The soil is of moderate extent.

Series Established: Bowman County, North Dakota, 1969.

Remarks: The Dilts soils would have been classified a Lithosol in the former system. It was formerly included with the Lismas series.

National Cooperative Soil Survey
U. S. A.

N00135

SOIL SURVEY INTERPRETATIONS

MLRA(S): 58
SCE-CAC. 12-74
USTIC TORRIORTHENTS, CLAYEY, MONTMORILLONITIC, ACID, FRIGID, SHALLOW

DILTS SERIES

THE DILTS SERIES CONSISTS OF SHALLOW, WELL DRAINED SOILS FORMED IN MATERIALS WEATHERED FROM CLAYSTONE, MUDSTONE AND SHALE. TYPICALLY, THESE SOILS HAVE OLIVE GRAY CLAY SURFACE LAYERS 5 INCHES THICK. THE UNDERLYING MATERIAL IS 14 INCHES OF OLIVE GRAY SHALY CLAY OVER CLAYSTONE. SLOPES RANGE FROM 0 TO 35 PERCENT. AREAS ARE USED AS RANGELAND.

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-5	C, SIC	CH	A-7	0	100	100	90-100	75-95	50-75	25-50
5-19	SH-C, C, SH-SIC	CH	A-7	0-5	90-100	75-100	60-100	55-95	50-75	25-50
19	WB									

DEPTH (IN.)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	CORROSIVITY STEEL	CORROSIVITY CONCRETE	EROSION FACTORS K	EROSION FACTORS T	WIND EROD. GROUP
0-5	<0.2	0.15-0.18	5.6-7.3	-	HIGH	HIGH	LOW	.32	2	4
5-19	<0.2	0.09-0.12	4.5-5.0	-	HIGH	HIGH	HIGH	.32		
19										

FLOODING FREQUENCY	FLOODING DURATION	FLOODING MONTHS	HIGH WATER TABLE DEPTH (FT)	HIGH WATER TABLE KIND	HIGH WATER TABLE MONTHS	CEMENTED PAN DEPTH (IN)	CEMENTED PAN HARDNESS	BEDROCK DEPTH (IN)	BEDROCK HARDNESS	SUBSIDENCE INIT. (IN)	SUBSIDENCE TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			-		10-20	RIPPABLE	-		D	LOW

SANITARY FACILITIES

SEPTIC TANK ABSORPTION FIELDS	0-15%: SEVERE-PERCS SLOWLY,DEPTH TO ROCK 15+%: SEVERE-PERCS SLOWLY,DEPTH TO ROCK, SLOPE
SEWAGE LAGOON AREAS	0-7%: SEVERE-DEPTH TO ROCK 7+%: SEVERE-DEPTH TO ROCK,SLOPE
SANITARY LANDFILL (TRENCH)	0-25%: SEVERE-TOO CLAYEY 25+%: SEVERE-TOO CLAYEY,SLOPE
SANITARY LANDFILL (AREA)	0-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
DAILY COVER FOR LANDFILL	0-15%: POOR-TOO CLAYEY,THIN LAYER 15+%: POOR-TOO CLAYEY,THIN LAYER,SLOPE

COMMUNITY DEVELOPMENT

SHALLOW EXCAVATIONS	0-15%: SEVERE-TOO CLAYEY 15+%: SEVERE-TOO CLAYEY,SLOPE
DWELLINGS WITHOUT BASEMENTS	0-15%: SEVERE-SHRINK-SWELL,LOW STRENGTH 15+%: SEVERE-LOW STRENGTH,SLOPE,SHRINK-SWELL
DWELLINGS WITH BASEMENTS	0-15%: SEVERE-SHRINK-SWELL,LOW STRENGTH 15+%: SEVERE-SHRINK-SWELL,LOW STRENGTH,SLOPE
SMALL COMMERCIAL BUILDINGS	0-8%: SEVERE-SHRINK-SWELL,LOW STRENGTH 8+%: SEVERE-SLOPE,SHRINK-SWELL,LOW STRENGTH
LOCAL ROADS AND STREETS	0-15%: SEVERE-SHRINK-SWELL,LOW STRENGTH 15+%: SEVERE-SHRINK-SWELL,LOW STRENGTH,SLOPE

REGIONAL INTERPRETATIONS

SOURCE MATERIAL

ROADFILL	0-25%: POOR-LOW STRENGTH,SHRINK-SWELL 25+%: POOR-LOW STRENGTH,SHRINK-SWELL,SLOPE
SAND	UNSUITED
GRAVEL	UNSUITED
TOPSOIL	0-15%: POOR-TOO CLAYEY 15+%: POOR-TOO CLAYEY,SLOPE

WATER MANAGEMENT

POND RESERVOIR AREA	DEPTH TO ROCK
EMBANKMENTS DIKES AND LEVEES	SHRINK-SWELL,COMPRESSIBLE,HARD TO PACK
EXCAVATED PONDS AQUIFIER FED	NO WATER
DRAINAGE	NOT NEEDED
IRRIGATION	PERCS SLOWLY,DEPTH TO ROCK
TERRACES AND DIVERSIONS	PERCS SLOWLY,DEPTH TO ROCK
GRASSED WATERWAYS	PERCS SLOWLY,ROOTING DEPTH

DILTS SERIES

ND0135

RECREATION

CAMP AREAS	0-15%: SEVERE-TOO CLAYEY 15+%: SEVERE-TOO CLAYEY, SLOPE	PLAYGROUNDS	0-6%: SEVERE-TOO CLAYEY, DEPTH TO ROCK 6+%: SEVERE-TOO CLAYEY, DEPTH TO ROCK, SLOPE
PICNIC AREAS	0-15%: SEVERE-TOO CLAYEY 15+%: SEVERE-TOO CLAYEY, SLOPE	PATHS AND TRAILS	0-25%: SEVERE-TOO CLAYEY 25+%: SEVERE-TOO CLAYEY, SLOPE

CAPABILITY AND PREDICTED YIELDS -- CROPS AND PASTURE (HIGH LEVEL MANAGEMENT)

CLASS-DETERMINING PHASE	CAPA-BILITY															
	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
0-25%	6S															
25+%	7S															

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	MANAGEMENT PROBLEMS					POTENTIAL PRODUCTIVITY		TREES TO PLANT
		EROSION HAZARD	EQUIP. LIMIT	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	IMPORTANT TREES	SITE INDX	
							NONE		

WINDBREAKS (A)

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
	NONE							

WILDLIFE HABITAT SUITABILITY

CLASS-DETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS								POTENTIAL AS HABITAT FOR:			
	GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
1-25%	POOR	POOR	POOR	-	-	POOR	V. POOR	V. POOR	POOR	-	V. POOR	POOR
25+%	V. POOR	V. POOR	POOR	-	-	POOR	V. POOR	V. POOR	V. POOR	-	V. POOR	POOR

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION) (B)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE				
		ALL				
WESTERN WHEATGRASS	AGSM	60				
GREEN NEEDLEGRASS	STVI4	5				
PLAINS MUHLY	MUCU3	3				
SIDEOATS GRAMA	BOCU	2				
PLAINS REEDGRASS	CAMO	2				
BLUE GRAMA	BOGR2	1				
SANDBERG BLUEGRASS	POSE	1				
OTHER PERENNIAL GRASSES	PPGG	9				
OTHER PERENNIAL GRASSLIKES	PPGL	2				
PRAIRIE THERMOPSIS	THRH	1				
POVERTY SUMPWEED	IVAX	1				
OTHER PERENNIAL FORBS	PPFF	3				
FRINGED SAGEBRUSH	ARFR4	1				
BROOM SNAKEWEED	GUSA2	1				
OTHER SHRUBS	SSSS	8				
POTENTIAL PRODUCTION (LBS./AC. DRY WT):						
FAVORABLE YEARS		1200				
NORMAL YEARS		1000				
UNFAVORABLE YEARS		800				

FOOTNOTES

A WINDBREAK GROUP 10, ND.
B SHALLOW CLAY RANGE SITE, ND.

USDA-SCS-LINCOLN, NEBR. 1975

APPENDIX A.3. HAVRELON SERIES.

Established Series
Rev. SRB
6/21/74

HAVRELON SERIES

The Havrelon series is a member of the fine-loamy, mixed (calcareous), frigid family of Typic Ustifluvents. Typically, these soils have light brownish gray silt loam Ap horizons and stratified loamy C horizons. The soils contain free carbonates throughout.

Typifying Pedon: Havrelon silt loam - on a level floodplain with less than 1 percent slope in a cultivated field
(Colors are for dry soil unless otherwise stated. Where described the soil was moist throughout.)

Ap -- 0-13"--Light brownish gray (2.5Y 6/2) silt loam, dark grayish brown (2.5Y 4/2) moist; cloddy separating to moderate medium granular structure; very friable; common roots; common fine pores; slight effervescence; mildly alkaline; abrupt smooth boundary. (8 to 15 inches thick)

C1 -- 13-18"--Grayish brown (2.5Y 5/2) silty clay loam, very dark grayish brown (2.5Y 3/2) moist; moderate medium granular structure; a thin lens of strong very fine platy structure; friable; common fine and few large roots, common fine pores; slight effervescence; mildly alkaline; abrupt smooth boundary. (0 to 8 inches thick)

C2 -- 18-26"--Light brownish gray (2.5Y 6/2) silt loam, dark grayish brown (2.5Y 4/2) moist; moderate medium granular structure; very friable; few roots; slight effervescence; mildly alkaline; clear smooth boundary. (6 to 12 inches thick)

C3 -- 26-40"--Light gray (2.5Y 7/2) and light brownish gray (2.5Y 6/2) very fine sandy loam, dark grayish brown (2.5Y 4/2) moist; massive with strata separating to weak or moderate fine platy structure; very friable; thin layers of fine sandy loam and silty clay loam; slight effervescence; mildly alkaline. (12 to 20 inches thick)

C4 -- 40-46"--Olive gray (5Y 5/2) silt loam and silty clay loam, olive gray (5Y 4/2) moist; common medium distinct reddish yellow (5YR 7/8) mottles; massive breaking to weak fine platy structure; friable; slight effervescence; mildly alkaline. (4 to 20 inches thick)

C5 -- 46-60"--Pale yellow (5Y 7/3) very fine sandy loam, olive (5Y 4/3) moist; massive; very friable; slight effervescence; mildly alkaline.

Type Location: Burleigh County, North Dakota; about 5 miles NW of Bismarck along River Road; 75 feet north and 75 feet east of the SW corner of the NW¼ of Sec. 2, T. 139 N., R. 81 W.

Range in Characteristics: The 10 to 40 inch control section typically is stratified with loam, silt loam or light clay loam materials averaging between 18 and 35 percent clay and more than 15 percent fine and coarser sand. Thin strata of sandy loam, clay or silty clay are common and thin layers of sand and fine gravel are in some pedons. Some strata have faint to distinct mottling. Organic matter varies widely and decreases irregularly with depth. Some pedons contain thin dark colored buried A horizons. The mean annual soil temperature is estimated to range from 40 to 47°F. The soil ranges from neutral to moderately alkaline. The A horizon has hue of 10YR or 2.5Y, value of 5 or 6 and 3 through 5 moist, and chroma of 1 or 2. Surface horizons having values as dark as 5 dry and 3 moist do not exceed 4 inches in thickness. The A horizon commonly is loam, silt loam or very fine sandy loam and less commonly fine sandy loam or clay loam. The C horizon has hue of 10YR, 2.5Y, or 5Y, value of 5 through 7 and 4 through 6 moist, and chroma of 1 through 3.

Competing Series and Their Differentiae: These are the Korchea and Shupert series in the same family and the Banks, Glendive, Haverson, Havre, Lohler, and Trembles series. Korchea soils have dark colored surface horizons 7 to 10 inches thick. Shupert soils are in areas with less than 100 days growing season at elevations above 6000 feet. Banks soils are sandy. Glendive and Trembles soils are coarse-loamy and in addition, the Glendive soils are usually dry. Haverson soils are mesic. Havre soils are usually dry. Lohler soils are fine.

Havrelon Series--2

Setting: Havrelon soils are on level floodplains of the Missouri River and its tributaries. Slope gradients are less than 1 percent. Micro-relief is in areas where floodwaters have filled and cut at different rates. The soil formed in loamy alluvium. The climate is cool semiarid. Mean annual temperature ranges from 38 to 45°F., and mean annual precipitation from 14 to 17 inches. Most of the precipitation comes in the spring and summer.

Principal Associated Soils: These are the competing Banks, Korchea, Lohler and Trembles soils and the Lallie and Straw soils. Banks soils are on levees adjacent to the streams and on sandy floodwater deposits. Korchea soils are on low terraces adjacent to the Havrelon soils. Lohler soils are on slightly lower elevations and typically at a greater distance away from the main stream channel than the Havrelon soils. The Trembles soils typically are on slightly higher elevations. Lallie soils are very poorly drained and are in low oxbows and abandoned channels. The Straw soils have mollic epipedons and are on low terraces.

Drainage and Permeability: Well drained. Occasionally flooded, usually in the early spring when snow melts. Runoff is slow or medium. Permeability is moderate.

Use and Vegetation: Cultivated areas are used for growing small grains, hay, corn, and pasture. Some areas are irrigated and cropped to sugar beets, potatoes, corn and alfalfa. Native grasses include Canada wildrye, big bluestem, green needlegrass and western wheatgrass. Trees including green ash, cottonwood, boxelder and chokecherry are along the stream channels.

Distribution and Extent: Central and western North Dakota and north central South Dakota. The series is of moderate extent.

Series Established: Burleigh County, North Dakota, 1970.

Remarks: The Havrelon soils would have been classified as Alluvial Soil in the former system.

National Cooperative Soil Survey
U. S. A.

APPENDIX A.3. (Cont.)

ND0065

SOIL SURVEY INTERPRETATIONS

MLRA(S): 53, 54
DGT, 1-74
TYPIC USTIFLUVENTS, FINE-LOAMY, MIXED (CALCAREOUS), FRIGID

HAVRELON SERIES

THE HAVRELON SERIES CONSISTS OF DEEP, WELL DRAINED SOILS FORMED IN RECENT LOAMY ALLUVIUM ON FLOODPLAINS. THE SURFACE LAYER IS LIGHT BROWNISH-GRAY SILT LOAM 13 INCHES THICK. THE UNDERLYING MATERIAL IS GRAYISH-BROWN, LIGHT BROWNISH-GRAY, LIGHT-GRAY, OLIVE-GRAY AND PALE-YELLOW STRATIFIED SILTY CLAY LOAM, SILT LOAM AND VERY FINE SANDY LOAM. SLOPES ARE LESS THAN 1 PERCENT. MOST AREAS ARE CROPPED.

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLAS-TICITY INDEX
0-13	SICL, SIL, L	ML, CL	A-4, A-6, A-7	0	100	100	85-100	60-95	25-45	5-30
0-13	FSL, VFSL	SM, ML	A-2, A-4	0	100	100	70-95	40-65	<35	NP-10
13-60	SR-SICL-VFSL	ML, CL	A-4, A-6, A-7	0	100	100	85-100	60-80	25-45	5-30

DEPTH (IN.)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	CORROSIVITY STEEL	CONCRETE	EROSION FACTORS K	T	WIND EROD. GROUP
0-13	0.6-2.0	0.20-0.24	7.4-7.8	-	MODERATE	HIGH	LOW	.28	5	4L
0-13	0.6-2.0	0.16-0.22	7.4-7.8	-	LOW	HIGH	LOW	.28	5	3
13-60	0.6-2.0	0.15-0.19	7.4-7.8	-	MODERATE	HIGH	LOW	.28		

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
COMMON	BRIEF	APR-JUN	4.0-5.0	APPARENT	SEP-JUN	-		>60		-		B	MODERATE

SANITARY FACILITIES (A)

SEPTIC TANK ABSORPTION FIELDS	COMMON: SEVERE-FLOODS, WETNESS PROTECTED: MODERATE-WETNESS
SEWAGE LAGOON AREAS	COMMON: SEVERE-FLOODS PROTECTED: MODERATE-WETNESS
SANITARY LANDFILL (TRENCH)	SEVERE-FLOODS, WETNESS
SANITARY LANDFILL (AREA)	COMMON: SEVERE-FLOODS PROTECTED: SLIGHT
DAILY COVER FOR LANDFILL	GOOD

COMMUNITY DEVELOPMENT

SHALLOW EXCAVATIONS	COMMON: SEVERE-FLOODS PROTECTED: MODERATE-WETNESS
DWELLINGS WITHOUT BASEMENTS	COMMON: SEVERE-FLOODS PROTECTED: MODERATE-SHRINK-SWELL, LOW STRENGTH
DWELLINGS WITH BASEMENTS	COMMON: SEVERE-FLOODS PROTECTED: MODERATE-WETNESS, SHRINK-SWELL, LOW STRENGTH
SMALL COMMERCIAL BUILDINGS	COMMON: SEVERE-FLOODS PROTECTED: MODERATE-WETNESS, SHRINK-SWELL, LOW STRENGTH
LOCAL ROADS AND STREETS	COMMON: SEVERE-FLOODS PROTECTED: MODERATE-FROST ACTION, LOW STRENGTH

REGIONAL INTERPRETATIONS

SOURCE MATERIAL

ROADFILL	FAIR-SHRINK-SWELL, FROST ACTION
SAND	UNSUITED
GRAVEL	UNSUITED
TOPSOIL	L, SIL, VFSL, FSL: GOOD SICL: FAIR-TOO CLAYEY

WATER MANAGEMENT

POND RESERVOIR AREA	SEEPAGE
EMBANKMENTS DIKES AND LEVEES	COMPRESSIBLE, PIPING, LOW STRENGTH
EXCAVATED PONDS AQUIFIER FED	SLOW REFILL
DRAINAGE	NOT NEEDED
IRRIGATION	FLOODS
TERRACES AND DIVERSIONS	PIPING
GRASSED WATERWAYS	NOT NEEDED

HAVRELON SERIES

ND0065

RECREATION

CAMP AREAS	COMMON: SEVERE-FLOODS PROTECTED, FSL, VFSL, L, SIL: SLIGHT PROTECTED, SICL: MODERATE-TOO CLAYEY	PLAYGROUNDS	COMMON: MODERATE-FLOODS PROTECTED, FSL, VFSL, L, SIL: SLIGHT PROTECTED, SICL: MODERATE-TOO CLAYEY
PICNIC AREAS	COMMON: MODERATE-FLOODS PROTECTED, FSL, VFSL, L, SIL: SLIGHT PROTECTED, SICL: MODERATE-TOO CLAYEY	PATHS AND TRAILS	L, SIL, VFSL, FSL: SLIGHT SICL: MODERATE-TOO CLAYEY

CAPABILITY AND PREDICTED YIELDS -- CROPS AND PASTURE (HIGH LEVEL MANAGEMENT) (B)

CLASS-DETERMINING PHASE	CAPABILITY		WHEAT, SPRING (BU)		OATS (BU)		BARLEY (BU)		FLAX (BU)		GRASS-LEGUME HAY (TONS)					
	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
L, SIL, VFSL, SICL	2E		29		58		49		14		2.1					
FSL	3E		27		55		45		13		2.0					

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	MANAGEMENT PROBLEMS: EROSION HAZARD	EQUIP. LIMIT	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	POTENTIAL PRODUCTIVITY: IMPORTANT TREES	SITE INDX	TREES TO PLANT
							NONE		

WINDBREAKS (C)

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
ALL	EASTERN COTTONWOOD	46	SIBERIAN ELM	30	AMERICAN ELM	23	GREEN ASH	23
	PONDEROSA PINE	23	BLACK HILLS SPRUCE	23	BLUE SPRUCE	23	COMMON CHOKECHERRY	16
	EASTERN REDCEDAR	16	SIBERIAN PEASHRUB	10	TATARIAN HONEYSUCKLE	10	AMERICAN PLUM	10

WILDLIFE HABITAT SUITABILITY

CLASS-DETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS								POTENTIAL AS HABITAT FOR:			
	GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
L, SIL, VFSL, SICL	GOOD	GOOD	FAIR	-	-	GOOD	POOR	V. POOR	GOOD	-	V. POOR	FAIR
FSL	FAIR	GOOD	GOOD	-	-	GOOD	POOR	V. POOR	GOOD	-	V. POOR	GOOD

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION) (D)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE: 13-17 MAP				
BIG BLUESTEM	ANGE	20				
GREEN NEEDLEGRASS	STUI4	15				
WESTERN WHEATGRASS	AGSM	20				
NEEDLEANDTHREAD	STCO4	5				
PORCUPINEGRASS	STSP2	3				
BLUE GRAMA	BOGR2	5				
KENTUCKY BLUEGRASS	POPR	3				
OTHER PERENNIAL GRASSES	PPGG	11				
PENN SEDGE	CAPE6	3				
OTHER PERENNIAL GRASSLIKES	PPGL	2				
STIFF SUNFLOWER	HERA	1				
MISSOURI GOLDENROD	SOMI2	2				
OTHER PERENNIAL FORBS	PPFF	5				
WESTERN SNOWBERRY	SYOC	2				
OTHER SHRUBS	SSSS	3				
POTENTIAL PRODUCTION (LBS./AC. DRY WT):						
FAVORABLE YEARS		3100				
NORMAL YEARS		2700				
UNFAVORABLE YEARS		2300				

FOOTNOTES

A MOST AREAS ON THE MISSOURI RIVER FLOODPLAIN BELOW GARRISON DAM ARE PROTECTED FROM FLOODING.
B PREDICTED YIELDS ARE FOR MLRA 53.
C NORTH DAKOTA WIND BREAK SUITABILITY GROUP.
D NORTH DAKOTA OVERFLOW RANGE SITE, COMPOSITION AND PRODUCTION GIVEN FOR LRA 54.

APPENDIX A.4. VANDA SERIES.

Established Series
Rev. COC/SHB
1/75

VANDA SERIES

The Vanda series consists of deep, well drained soils that formed in alluvium from sedimentary uplands or from glacial meltwater deposits. These soils are nearly level or gently sloping and are on fans or terraces. The mean annual precipitation is about 12 inches and the mean annual air temperature is about 42°F.

Soil Family: Fine, montmorillonitic (calcareous), frigid Ustic Torriorthents.

Typical Pedon: Vanda clay, cultivated. (Colors are for dry soil unless otherwise noted.)

Ap—0 to 4 inches, light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) moist; a 3- to 5-mm. massive crust over weak very fine granular structure; very hard, friable, very sticky and very plastic; many fine and very fine vesicular pores; slightly effervescent; strongly alkaline (pH 8.6); abrupt wavy boundary. (4 to 6 inches thick)

C1—4 to 12 inches, light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) moist; massive; extremely hard, firm, very sticky and very plastic; common fine and very fine roots; common fine and very fine pores; slightly effervescent; strongly alkaline (pH 8.8); clear wavy boundary.

C2cs—12 to 60 inches, light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) moist; massive; extremely hard, firm, very sticky and very plastic; few fine and very fine roots; common fine and very fine pores; many fine and medium masses of gypsum; slightly effervescent; moderately alkaline (pH 8.4).

Type Location: Cascade County, Montana; 800 feet north and 50 feet west of the SE corner of sec. 8, T.21N., R.2E.

Range in Characteristics: Depth to segregated gypsum is 11 to 20 inches. The mean annual soil temperature is 42° to 47°F. The 10- to 40-inch control section is clay or silty clay and averages 35 to 60 percent clay. The soil has hue of 2.5Y or 5Y. Uncultivated areas have a thin (less than 2 inches) gray clay or silty clay A2 horizon on the surface of some pedons and some have a light gray surface crust. The upper 6 inches is noncalcareous in some pedons.

The Ap horizon has value of 5 through 7 dry, 4 or 5 moist and chroma of 1 through 3. It is silty clay or clay.

The C horizon has value of 5 or 6 dry, 4 or 5 moist, and chroma of 2 or 3. It is massive or has weak blocky structure. This horizon has slight to moderate effervescence and has pH value of 8.2 to 10.0. The upper part of the C horizon has an estimated exchangeable Na percentage of 8 to 15. The lower part has few to many segregated masses of gypsum and few to common segregations of soluble salts and has an estimated range of 20 to 30 percent exchangeable Na. Some pedons have stratifications of coarser material below depth of 30 inches.

Competing Series: These are the Dollard, Nobe and Sunburst series in the same family and the Absher, Arvada, Bone and Vananda series that are closely related. Absher and Arvada soils have natric horizons. Arvada, Bone and Vananda soils have annual soil temperature warmer than 47°F. Dollard soils have bedrock at depths of 20 to 40 inches. Bone and Nobe soils have thin B2t horizons and have 2 to 3 percent soluble salt at shallow depths. Sunburst soils are deeper than 24 inches to segregated gypsum.

Geographic Setting: Vanda soils are nearly level or gently sloping and are on fans and terraces at elevations of 2,300 to 4,000 feet. They formed in fine textured alluvium mainly from sedimentary uplands or glacial meltwater deposits. The climate is cool, dry-semiarid with cold dry winters and moist springs and summers. The mean annual temperature is 40° to 45°F. The mean annual precipitation is 10 to 15 inches, most of which falls in the spring and early summer. The (32°F.) growing season is 90 to 135 days.

Associated Soils: These are the Abor, Marvan and Thebo soils and the competing Absher, Nobe and Sunburst soils. Abor and Thebo soils have bedrock at depths of 20 to 40 inches. Marvan soils have a granular surface.

Drainage and Permeability: Well drained; slow or medium runoff; very slow permeability.

Use and Vegetation: Vanda soils are used mainly for range. The native vegetation is primarily sparse stands of western wheatgrass, greasewood, inland saltgrass and Gardner's saltbrush.

Distribution and Extent: The eastern plains of Montana and possibly North Dakota, South Dakota and Wyoming. These soils are extensive.

Series Established: Blaine County, Montana, 1969.

Remarks: Vanda soils were formerly classified as Solonetz soils.

National Cooperative Soil Survey
U. S. A.

MT0023

SOIL SURVEY INTERPRETATIONS

MLRA(S): 53, 59
REV. 3-75
USTIC TORRIORTHENTS, FINE, MONTMORILLONITIC (CALCAREOUS), FRIGID

VANDA SERIES

THE VANDA SERIES CONSISTS OF DEEP, WELL-DRAINED SOILS FORMED IN CLAYEY ALLUVIUM. TYPICALLY THESE SOILS HAVE A CLAY TEXTURE THROUGHOUT THE PROFILE. THEY OCCUPY FANS AND TERRACES IN A 10 TO 15 INCH PRECIPITATION ZONE. SLOPES ARE 0 TO 4 PERCENT. THE NATIVE VEGETATION IS MAINLY MID AND SHORT GRASSES. THE GROWING SEASON IS 90 TO 135 DAYS.

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-4	C	CL, CH	A-7	0	100	100	90-100	75-95	45-60	30-40
4-60	C, SIC	CL, CH	A-7	0	100	100	90-100	80-95	45-60	30-40

DEPTH (IN.)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	CORROSIVITY STEEL	CORROSIVITY CONCRETE	EROSION FACTORS K	EROSION FACTORS T	WIND EROD. GROUP
0-4	<0.06	0.10-0.14	>8.4	8-16	HIGH	HIGH	LOW	.24	5	8
4-60	<0.06	0.10-0.14	>8.4	8-16	HIGH	HIGH	LOW	.24		

FLOODING FREQUENCY	FLOODING DURATION	FLOODING MONTHS	HIGH WATER TABLE DEPTH (FT)	HIGH WATER TABLE KIND	HIGH WATER TABLE MONTHS	CEMENTED PAN DEPTH (IN)	CEMENTED PAN HARDNESS	BEDROCK DEPTH (IN)	BEDROCK HARDNESS	SUBSIDENCE INIT. (IN)	SUBSIDENCE TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			-		>60		-		D	LOW

SANITARY FACILITIES

SEPTIC TANK ABSORPTION FIELDS	SEVERE-PERCS SLOWLY
SEWAGE LAGOON AREAS	0-2%: SLIGHT 2+%: MODERATE-SLOPE
SANITARY LANDFILL (TRENCH)	SEVERE-TOO CLAYEY
SANITARY LANDFILL (AREA)	SEVERE-TOO CLAYEY
DAILY COVER FOR LANDFILL	POOR-TOO CLAYEY,AREA RECLAIM

COMMUNITY DEVELOPMENT

SHALLOW EXCAVATIONS	SEVERE-TOO CLAYEY
DWELLINGS WITHOUT BASEMENTS	SEVERE-SHRINK-SWELL,LOW STRENGTH
DWELLINGS WITH BASEMENTS	SEVERE-SHRINK-SWELL,LOW STRENGTH
SMALL COMMERCIAL BUILDINGS	SEVERE-SHRINK-SWELL,LOW STRENGTH
LOCAL ROADS AND STREETS	SEVERE-SHRINK-SWELL,LOW STRENGTH

REGIONAL INTERPRETATIONS

SOURCE MATERIAL

ROADFILL	POOR-SHRINK-SWELL,LOW STRENGTH
SAND	UNSUITED
GRAVEL	UNSUITED
TOPSOIL	POOR-TOO CLAYEY,EXCESS SODIUM

WATER MANAGEMENT

POND RESERVOIR AREA	FAVORABLE
EMBANKMENTS DIKES AND LEVEES	LOW STRENGTH,HARD TO PACK,COMPRESSIBLE
EXCAVATED PONDS AQUIFIER FED	NO WATER
DRAINAGE	
IRRIGATION	
TERRACES AND DIVERSIONS	PERCS SLOWLY,POOR OUTLETS
GRASSED WATERWAYS	EXCESS SODIUM,PERCS SLOWLY

APPENDIX A.4. (Cont.)

VANDA SERIES

MT0023

RECREATION

CAMP AREAS	SEVERE-TOO CLAYEY,PERCS SLOWLY	PLAYGROUNDS	SEVERE-PERCS SLOWLY,TOO CLAYEY
PICNIC AREAS	SEVERE-TOO CLAYEY	PATHS AND TRAILS	SEVERE-TOO CLAYEY

CAPABILITY AND PREDICTED YIELDS -- CROPS AND PASTURE (HIGH LEVEL MANAGEMENT)

CLASS-DETERMINING PHASE	CAPABILITY															
	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
ALL	6E															

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	MANAGEMENT PROBLEMS					POTENTIAL PRODUCTIVITY		TREES TO PLANT
		EROSION HAZARD	EQUIP. LIMIT	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	IMPORTANT TREES	SITE INDX	
							NONE		

WINDBREAKS

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
	NONE							

WILDLIFE HABITAT SUITABILITY

CLASS-DETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS								POTENTIAL AS HABITAT FOR:			
	GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
ALL	POOR	FAIR	V. POOR	-	-	V. POOR	POOR	V. POOR	POOR	-	V. POOR	V. POOR

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE				
		10-15 MAP				
WESTERN WHEATGRASS	AGSM	80				
NUTTALL ALKALIGRASS	PUAI	3				
BOTTLEBRUSH SQUIRRELTAIL	SIHY	2				
GREASEWOOD	SARCO	3				
SILVER SAGEBRUSH	ARCA13	2				
OTHER ANNUAL GRASSES	AAGG	5				
OTHER ANNUAL FORBS	AAFF	5				
POTENTIAL PRODUCTION (LBS./AC. DRY WT):						
FAVORABLE YEARS		800				
NORMAL YEARS						
UNFAVORABLE YEARS		400				

FOOTNOTES

APPENDIX B. SOIL AND OVERBURDEN GUIDELINES.

APPENDIX B.1.

Analyses for characterizing soil and overburden samples

Soil or overburden	Reported as	Importance of and/or use	Acceptable procedure[1]
Salinity-Exchangeable Sodium-Related Analyses and Calculations:			
Saturated paste	Water saturation – % (SP)	Measure of maximum moisture retention of pulverized (<2 mm) soil or overburden; 1/2 SP gives an estimate of field capacity of unconsolidated material; 1/4 SP gives an estimate of wilting point of unconsolidated material.	USDA Agric. Handb. 525, No. 2, p. 4-6.
Reaction (acidity or alkalinity)	pH of saturated paste (pH_s); pH of dilute soil: water suspension, usually 1:5 (pH_d); pH is the negative log of hydrogen in activity.	Soil pH aids diagnosis of many different soil problems, such as an indication of free lime or excessive exchangeable sodium; pH is not very reliable when used as the only diagnostic criteria.	USDA Agric. Handb. 525, No. 4, p. 6.
Electrical conductivity saturated paste extract	mmhos/cm 2 25°C ($ECx10^3$)	Rapid measure of water soluable salt content.	USDA Agric. Handb. 525, No. 1, p. 22.
Water soluable cations (Ca, Mg, Na, K)	meq/l; p/m meq/100 g	Indication of cation distribution in soil solution and on cation exchange complex; assessment of salinity and fertility relationships.	USDA Agric. Handb. 525, No. 2, 3, 4; p. 24-27.
Sodium adsorption ratio (SAR)	$\frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$ (calculated in me/1)	Estimation of percent exchangeable sodium (ESP).	USDA Agric. Handb. 60, No. 20b, p. 102.
Potassium adsorption ratio (PAR)	$\frac{K}{\sqrt{\frac{Ca + Mg}{2}}}$	Estimation of percent exchangeable potassium (EPP).	USDA Agric. Handb. 60, No. 20b, p. 102.
Water soluble anions (CO_3, HCO_3, SO_4, C1, NO_3, B)	meq/l, p/m; meq/100 g	Indication of anion distribution in soil solution; assessment of salinity-fertility relations.	USDA Agric. Handb. 525, No. 5, 6, 7, 11, 12; p. 16-18, 20-22, 27-30.
Ammonium acetate extractable cations (Na, K)	meq/100 g	Determination of exchangeable sodium and potassium.	USDA Agric. Handb. 525, No. 5, p. 7-8.
Cation exchange capacity[2] (CEC)	meq/100 g	Measure of total cation retention.	USDA Agric. Handb. 525, No. 5B, p. 8-9.
Exchangeable sodium percentage (ESP)	Percent	Measure of percent sodium on cation exchange capacity (not reliable for material containing sodium-zeolite).	USDA Agric. Handb. 525, No. 6, p. 9.
Exchangeable potassium percentage (EPP)	Percent	Measure of percent potassium on cation exchange capacity.	USDA Agric. Handb. 60, No. 20, p. 101.
Gypsum	meq/100 g; percent	Measure of solid phase gypsum content.	USDA Agric. Handb. 525, No. 7, p. 10-11.
Fertility-related analyses:			
Calcium carbonate equivalent	Percent; meq/100 g	Measure of alkaline-earth carbonates.	USDA Agric. Handb. 525, No. 3, p. 6.
Organic carbon[3]	Percent (readily oxidized carbonaceous residue of plant material).	Assessment of N and S fertility; stability of soil aggregates.	USDA Agric. Handb. 525, No. 8, p. 12-13.
Total nitrogen	Percent, p/m	Assessment of N-cycling potential in terms of C/N.	USDA Agric. Handb. 525, No. 10, p. 14-16.
Acid permanganate oxidizable soil nitrogen	p/m	Assessment of potentially mineralizable soil nitrogen.	Stanford and Smith, 1978.
Ammonium, nitrate and nitrite	p/m, meq/100 g	Indication of plant available nitrogen.	USDA Agric. Handb. 525, No. 10B, p. 18-20.
Available phosphorus	p/m	Plant availability index.	USDA Agric. Handb. 525, No. 9, p. 13-14; Watanabe and Olsen (1965).
Available potassium	p/m	Plant availability index.	ASA Monograph No. 9, Part 2. Pratt (1965), p. 1027-1030.
DTPA extractable zinc, iron, manganese, and copper	p/m	Plant availability index.	Lindsay and Norvell (1978).

APPENDIX B.1. (Cont.)

Soil or overburden	Reported as	Importance of and/or use	Acceptable procedure[1]
Toxicity-related analyses:			
Active sulfides (qualitative)	Present or absent	Acidification potential.	Neckers and Walker (1952).
Total sulfur	p/m, percent	Assessing acid-base potential.	ASA Monograph No. 9, Part 2. Bardsley and Lancaster, 1965, p. 1103-1108; Steinbergs, and others. (1962).
Acid-base account	Tons per 1,000 tons	Assessment of neutralization of potential acidity by lime.	Smith and others, (1976), p. 293[4]
Elemental analysis	p/m, percent	Screening for potential heavy metal or other elemental toxicity.	X-ray Spectroscopy, ASA Monograph No. 9, Part 2 Vanden Heuvel (1965), p. 771-819.
Hot water soluble Se	p/m	Assessment of plant toxicity.	ASA Monograph No. 9, Part 2 Fine (1965), p. 1122.
Ammonium oxalate extractable MO	p/m	Assessment of plant toxicity.	ASA Monograph No. 9, Part 2 Reisenauer (1965), p. 1054.
Hot water soluble boron	p/m	Assessment of B-toxicity.	USDA Agric. Handb. 525, No. 12, p. 20-22.
DTPA extractable zinc, iron, manganese, copper, cadmium (and probably other heavy metals.	p/m	Assessment of ion toxicities to plants.	Lindsay and Norvell (1978); Korcak and Fanning (1978).
Physical analyses:			
Particle size analyses	Percent sand, silt, clay (also very fine sand)	Assessment of erosiveness, permeability, water holding capacity, capillary potential inherent fertility.	ASA Monograph No. 9, Part 1 Day (1965), p. 545-566.
Texture	sand, loamy sand, sandy loam, loam, silt loam, sandy clay loam, silty clay loam, clay loam, clay	Assessment of generalized moisture, fertility, and salinity relations.	USDA Texture Classification.
Shrink-swell	Low, medium, high	Assessment of permeability hazard.	ASA Monograph No. 9, Part 1 Holtz (1965), p. 461-63.
Slaking test	Percent particles passing screen	Assessment of induration.	Modification of Smith and others, (1976) vol. 2 (this report).
Mineralogical analyses:			
Pyrite identification	Euhedral phenocrysts, Framboidal; percent; present or absent; size	Assessment of acidification potential and salinity increases.	Petrographic analysis; X-ray diffraction, electron microscopy (Arora and others, 1978).
Clay mineralogy	Clay mineral type; percent	Evaluate moisture and fertility relationships, strata.	ASA Monograph No. 9, Part 1 Ch. 44, 45, 49; p. 568-601, 611-696.
Sand mineralogy	Mineral, matrix, and cement percentages	Evaluate weatherability, strata, and fertility.	ASA Monograph No. 9, Part 1 (1965), p. 604-630.

[1] Reference citations given in literature citation section.

[2] Dispersion of overburden samples by ultrasonic frequency is recommend.

[3] Reagents oxydize reduced sulfides and give high results.

[4] Water soluble sulfate and gypsum should be deducted from total sulfur.

Source: Barrett 1980.

APPENDIX B.2.

SUITABILITY OF TOPSOIL, SUBSOIL, AND OVERBURDEN FOR REVEGETATION OF REGRADED SURFACE MINES UNDER NON-IRRIGATED CONDITIONS IN ARID AND SEMIARID REGIONS

Factor	Material	Highly suitable (excellent to good)	Suitable (fair)	Undesirable except with amelioration (poor)	Amelioration
$EC_{se}X10^3$ mmhos/cm	Topsoil (A-horizon)	<2	2-4[1]	>4[1]	Leaching to reduce <4
ESP	Topsoil (A-horizon)	<5	5-10	>10	Amendment to reduce[2] ESP to <10
$EC_{se}X10^3$ mmhos/cm	Subsoil (B & C horizons)[3]	<4	4-8	8	Leaching to reduce to <8
ESP	Subsoil (B & C horizons)	<10	10-15	15-30[4]	Amendment to reduce[2] ESP to <15
ESP	Subsoil (B & C horizons) 2:1 swelling clay content >65% of <2 fraction	<5	5-10	10-15	Amendment to reduce[2] ESP to <10
$EC_{se}X10^3$ mmhos/cm	Overburden (B & C horizon contact material)	<4	4-8	>8[1]	Leaching
ESP	Overburden (B & C horizon contact material)	<10	10-15	15-30[4]	Amendment to reduce[2] ESP to <15
$EC_{se}X10^3$ and ESP	Overburden as substitute for topsoil or subsoil (B & C horizon)	Same EC & ESP criteria as topsoil and subsoil			

Source: Barrett _et al_. 1980.

[1] Changes to suitable with supplementary irrigation water having $ECX10^6$ <1000 mmhos/cm and SAR <5 or annual precipitation >18 inches.

[2] Amendment alternatives: native gypsum, commercial gypsum, commercial low-B $CaCl_2$.

[3] Minimum thickness of overlying A not <6 inches (15 cm).

[4] 2:1 swelling clay content 65% of <2 fraction -- reduce to topsoil value if >65%.

APPENDIX B.3.

SUITABILITY RATINGS OF SOIL (TO DEPTH OF 1 METER) FOR USE AS A PLANT GROWTH MEDIUM IN DRASTICALLY DISTURBED LAND RECLAMATION

DOMINANT LAYERS IN UPPER METER OF SOIL (WHEN APPLIED TO PHASE OF SOIL SERIES)

FACTORS AFFECTING USE	DEGREE OF SUITABILITY		
	GOOD	FAIR	POOR (Essentially unsuitable)
EC (mmhos/cm)	<8	8-16	>16
SAR	<2	2-12	>12
ESP 1/	<2	2-15	>15
pH	5.0 - 8.5	3.5 - 5.0	<3.5; >8.5
Coarse Fragments over 3 inch diameter (percent by volume)	<15	15-35	>35
Intermediate Textural Group	medium moderately fine moderately coarse	fine	coarse
Available Water Capacity (inches/inch)	>.1	.1 - .05	<0.5
Depth to Bedrock or cemented pan	>40"	20 - 40"	<20"
Slope (%)	<8	8-15	>15

1/ Rate 2:1 Clay texture poor if over 10; Sand texture if over 20.

For other overburden, disregard slope and depth to bedrock and add consideration for sulphides and toxic materials.

When rating overburden, EC, SAR, pH and texture are used from the table.

Source: EMRIA 1977.

APPENDIX B.4.

Required Modifications and Additions in the Soil and Soil Analysis for the Montana State Land Department Soils and Overburden Guidelines

Mapping units must consist primarily of consociations but the use of complexes is allowable where it is impossible to cartographically accomplish separation at a scale of 1" to 400 ft. Under no circumstances is the use of miscellaneous land types acceptable. The slope divisions utilized in the inventory must conform to those found in the Standard Soil Survey Legend in the county or survey area in which the study is taking place. Soil phases must be recognized and described in accordance with and including all types established by the Soil Survey Handbook (1951) and the Standard Soil Survey Legend. A compilation of the acreage and extent of each mapping unit must be made.

The maximum allowable inclusion of a highly contrasting soil type or phase is 10 percent.* Areas of minor or included highly contrasting soils that are one-half (1/2) acre or larger in size and low contrasting soils of two (2) acres or larger in size must be delineated on the soil map.

All soil taxonomic units appearing in the soil survey legend are to be described, sampled by genetic horizons and characterized. All taxonomic units are to be classified at the subgroup and family level according to the Soil Taxonomy (1975). The same units need to be described as to competing and geographically related series. Interpretative guidelines need to be developed for each of the mapping units appearing in the survey legend. Parameters to be evaluated include suitability as a source of gravel or road fill, soil features affecting highway location, farm ponds-reservoir area and embankment, building sites, limitations for use for sewage disposal fields and corrosivity of untreated steel pipes. Predicted average yield per acre under a high level of management must be presented for each mapping unit. These units should be assigned a land capability unit in accordance with the Land Capability Classification System (SCS-USDA) and a range site correlation. Each master horizon must be evaluated for topsoil and/or subsoil materials for reclamation.

All soil sampling must be accomplished from pits, with a sample collected from each genetic soil horizon. All samples and containers must be identified by code numbers only. Twenty (20) percent of soil samples need to be collected in duplicate by random selection of code numbers. Ten (10) percent of the samples collected have to be submitted in duplicate to the laboratory carrying out the overall analytical program. Ten (10) percent of the samples collected must be submitted to a different laboratory facility. Results from these studies are to be mailed directly to the Department of State Lands as well as to the contractor.

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*Highly contrasting soils are those differing in texture of argillic horizon or control section at the level of contrasting textures in the Soil Taxonomy (1975): Mollisols vs. Aridisols and Orthents, Pachic and Cumulic phases of Mollisols; Fluvents; Lithic and Natric. Those characteristics not qualifying as highly contrasting are considered low contrasting soils.

The project area must be flown for aerial photography with the negatives having a scale not smaller than 1" to 1000 feet. The existing enlargements made from USDA-ASCS photography are so poor in quality that they could and do represent a major source of survey error working at the intensity of current Department of State Lands guidelines or those proposed in this document. Controlled mosaics should be constructed and utilized to produce a map having a minimum of distortion and problems in joining maps.

Field reviews by qualified soil scientists should be considered mandatory during all phases of the soil inventory effort. A final review of the results must be made after completion of both field and laboratory studies. It is highly recommended that a cooperative agreement be reached between the Montana Department of State Lands, Soil Conservation Service and the Cooperative Soil Survey Program of the Agricultural Experiment Station at Montana State University to provide highly qualified and experienced personnel to conduct the reviews. An agreement of this type would insure a quality product for the State of Montana and the applicant at a lesser cost than by other methods such as gridding the area on 200-ft. or less intervals and logging data on all holes examined.

Source: S. Fisher 1977.

APPENDIX B.5.

June 30, 1977

MEMO

TO: Interested Parties

FROM: Neil Harrington

RE: Suspect Levels of Soil Parameters

Following are suspect levels of various chemical and physical constituents of soils and overburden as determined by methods and procedures of resource guidelines established by the Coal and Uranium Bureau, Department of State Lands:

Parameter	Suspect Level
pH	8.8 - 9.0
Conductivity (mhos/cm)	4 - 6
SAR	12
Texture	40% Clay
	loamy sand and sand
Boron	8 ppm
Cadmium	0.1 - 1 ppm
Copper	40 ppm
Iron	a)
Lead	(pH<6 (10-15); pH>6 (15-20)
Manganese	60 ppm
Mercury	400-500 ppb
Molybdenum b)	0.3 ppm
Nickel	1.0 ppm
Selenium	2.0 ppm
Zinc	40 ppm
Ammonium - Nitrogen	c)
Nitrate - Nitrogen	c)

a) The primary reason for including iron is that it is a chemical antagonist of various other potentially toxic trace elements. Thus its level may be a mitigating feature relative to other metals. On the other hand, high levels of some trace elements may depress iron availability to deficiency levels. A suspect level of iron has not been defined.

b) The standard for molybdenum is in reference to animal consumption of vegetation which may accumulate to levels that may be toxic to these animals. In actuality, the Cu:Mo ratio in the vegetation is the parameter of direct relevance here.

c) The significance of ammonium and nitrate stems from the water pollution potential of nitrate. The federal drinking water standard is 10 ppm nitrate - nitrogen and the federal livestock threshold concentration is 50 ppm nitrate - nitrogen. Ammonium can be biologically oxidized to nitrate if conditons are suitable.

The suspect levels are not hard and fast rules since a potentially undesirable level may be dependent on other chemical and physical properties. For example, the availability of a trace element to plants can be dependent on pH, organic matter content, the level of other trace elements and/or macronutrients, and the plant species growing on regraded and retopsoiled spoils. Sandy soil textures would allow the SAR suspect level to rise. The position and thickness of a layer containing undesirable material would also be determining factors as to the final interpretation of whether this layer would, in fact, present a hazard, since mixing with adjacent layers or burial in the normal course of mining might be accomplished.

APPENDIX B.6.

PROPOSED GUIDELINES FOR RATING THE SUITABILITY OF SELECTED OVERBURDEN FOR USE AS COVER-SOIL MATERIAL IN STRIPMINE RECLAMATION

Factor Affecting Use	Good	Fair	Poor	Methods
Texture class	vfsl, fsl, sl, l, sil	lfs, ls, cl, scl, sicl	s, c, sc, sic	See Table 1
EC (mmhos/cm)	<4	4-8	>8	See Table 1
ESP	0-5	5-15	>15	See Table 1
Material or rock type	Weakly consolidated sandstones & siltstones & unconsolidated surface deposits (i.e., loess; till; recent alluvium; and colluvium)		Indurated sandstone & siltstone, shale, clayey or gravelly material	Observatin
Water slaking[†]	2-10		0-2	See ref. 22
Trace elements[‡]	Less than limits at right		ppm B > 8 Cd > 0.1-10 Cu > 40 Fe[§] Pb > 10-20 Mn > 60 Hg > 0.4-0.5 Mo > 0.3 Ni > 1.0 Se > 2.0 Zn > 40.0	

Modified from Schafer 1979.

[†] Other tests may be suitable. At least 30% of material should weather into <2 mm particles within 1 year in the surface 10 cm. A rating of 0-2 in the slaking test indicates that 0-20% of a fragment has passed a 5-mm sieve after 30 minutes submerged in water.

[‡] Selected trace elements should be analyzed from this list if they are a demonstrated regional problem or if required by state or Federal law. Many quantitative limits shown in this section are not supported by research findings. Measurement of these elements is costly and should be considered optional.

[§] Iron is analyzed because of antagonism with other nutrients. High Fe may mitigate high levels of other metals. Iron deficiency could also occur.

APPENDIX B.7.

PROPOSED GUIDELINES FOR RATING THE SUITABILITY OF TOPSOIL AND SUBSOIL FOR USE AS COVER-SOIL MATERIAL IN STRIPMINE RECLAMATION.

Factors Affecting Suitability of Soil Material	Good	Fair†	Poor‡	Methods
Texture class	vfsl, fsl, sl, l, sil	lfs, ls, cl, scl, sicl	s, c, sc, sic	ASA. Agron. Mono. Methods of Soil Analysis II. 75-4. pp. 1062-1063
Moist consistence	vfr, fr	lo, fi	vfi, exfi	Soil Survey Manual. p. 233.
EC (mmhos/cm)	<4	4-8	>8	USDA Hndbk. 60. pp. 88-89.
ESP	0-5	5-15	>15	Soil Survey Investigations. Rpt. 1. p. 21. Method 5D1.
pH	5.6-7.8	4.5-5.6; 7.8-8.4	<4.5, >8.4	Soil Survey Investigations. Rpt. 1. p. 59. Method 8c1a. Use indicator dyes for field estimate.
Stoniness class	0	1	2-5	Soil Survey Manual. pp. 217-219.
Available water	>10	5-10	<5	Soil Survey Investigations. Rpt. 1. p. 14 Method 4C1.
Rock fragments (%)	<15	15-35	>35	Estimate
Saturation water (%)		25-80	<25; >80	USDA Hndbk. 60. p. 84 Method 2, 3a.

Modified from Schafer 1979.

†Mitigation of adverse properties will increase reclamation potential.
‡Materials rated as poor may be suitable as topsoil only if adverse factor can be treated.
§Numbers relate to references at the end of this report.

APPENDIX B.8.

Soil Reconstruction Material for Drastically Disturbed Areas. Soil reconstruction of areas drastically disturbed, as in surface mining, is the process of replacing layers of soil material or unconsolidated geologic material or both in a vertical sequence of such quality and thickness that they provide a favorable medium for plant growth.

Most new state strip mine programs emphasize that the land surface be restored to about its natural configuration or better and the soil be reconstructed to maintain or improve its suitability for the intended use. Thus, a knowledge of the soil and underlying material is needed to plan proper reconstruction operations of mined land. This guide for soil reconstruction material evaluates the material as a medium for plant growth. It can be used to rate any segment of the soil profile or unconsolidated geologic material that is thick enough to warrant considerations in planning soil reconstruction. For named kinds of soil, for example, it will be necessary for most purposes to rate the A horizon, the B horizon, and the C horizon separately. If they all rate "good" there may be little justification for keeping them separate for soil reconstruction. If the A is rated better than the B or C, then it generally should be kept separate, depending upon its thickness and the anticipated use of the land. This guide does not cover quarry, pit, dredge, and older surface mine operations that require an off-site source of soil reconstruction material--the guide "Daily Cover for Sanitary Landfill" is useful to evaluate the material used in restoration of these operations.

When the soil materials are properly used in reconstruction, a good rating means vegetation is relatively easy to establish and maintain, the surface is stable and resist erosion, and the reconstructed soil has good potential productivity. Material rated fair can be vegetated and stabilized by modifying one or more properties. Top dressing with better material or application of soil amendments may be necessary for satisfactory performance. Material rated poor has such severe problems that revegetation and stabilization is very difficult and costly. Top dressing with better material is necessary to establish and maintain vegetation.

The major properties that influence erosion and stability of the surface and the productive potential of the reconstructed soil are listed in the guide.

Excessive amounts of substances that restrict plant growth such as sodium, salt, sulfur, copper, and nickel create problems in establishing vegetation and therefore, also influence erosion and the stability of the surface. Other substances such as selenium, boron, and arsenic get into the food chain and are toxic to animals that eat the vegetation. Of all these substances, only sodium and salt are criteria in the guide. If relatively high levels of toxic substances are in the reconstruction material, the material should be rated poor. Laboratory tests may be needed to properly identify toxic substances.

Source: Soil Survey Staff 1978. National Soils Handbook--Notice No. 24.
USDA, Soil Conservation Service, Washington, D.C.

APPENDIX B.8. (Cont.)

SOIL RECONSTRUCTION MATERIAL FOR DRASTICALLY DISTURBED AREAS

	PROPERTY	LIMITS			RESTRICTIVE FEATURE
		GOOD	FAIR	POOR	
1.	SODIUM ADSORPTION RATIO	<5	5-12	>12	EXCESS SODIUM
2.	SALINITY (MMHOS/CM)	<8	8-16	>16	EXCESS SALT
3.	TOXIC MATERIALS	LOW	MEDIUM	HIGH	TOXICITY
4.	SOIL REACTION (pH)[29/]	5.6-7.8	4.5-5.5	<4.5	TOO ACID
5.	SOIL REACTION (pH)	---	7.9-8.4	>8.4	EXCESS LIME
6.	AVAILABLE WATER CAPACITY (IN/IN)	> .10	.05-.10	< .05	DROUGHTY
7.	EROSION FACTOR (K)	<.37	>.37	---	ERODES EASILY
8.	WIND EROD. GROUP	> 3	>3	1, 2	SOIL BLOWING
9.	USDA TEXTURE	---	SCL, CL SICL	C[4/] SIC[4/] SC	TOO CLAYEY
10.	USDA TEXTURE	---	LCOS, LS LFS, LVFS	COS, S, FS, VFS	TOO SANDY
11.	COARSE FRAG. (WT PCT)				
	3-10 in.	<15	15-35	> 35	LARGE STONES
	>10 in.	<3	3-10	> 10	LARGE STONES

[29/] Layers with high potential acidity should be rated poor.

[4/] If in kaolinitic family, rate one class better if experience confirms.

Materials that are extremely acid or have the potential upon oxidation of becoming extremely acid are difficult and expensive to vegetate, and contribute to poor quality of water, both in runoff or in ground water. Materials high in pyrite and marcasite without off-setting bases have high potential acidity. Laboratory tests may be needed to properly identify these materials.

Vegetation is difficult to establish on soils with high pH. Many of these soils also have a high sodium adsorption ratio which indicates potential instability and water transmission problems.

Available water capacity also is important in establishing vegetation. Soils with low available water capacity may require irrigation for establishment of vegetation.

The stability of the soil depends upon its erodibility by water and wind and its strength. Water erodibility is indicated by the K factor; wind erodibiltiy is rated according to the wind erodibility group. Potential slippage hazard is related to soil texture, and although other factors also contribute, the ratings of soil texture represent one important factor.

USDA texture also influences a number of properties listed above such as available water capacity and erodibility by wind or water. Texture also influences soil structure and consistence, water intake rate, runoff, fertility, workability, and trafficability.

Fraction >3 inches is a weight percentage of rock fragments in the material used for soil reconstruction. Rock fragments influence the ease of excavation, stockpiling and respreading, and suitability for the final use of the land. A certain amount of rock fragments can be tolerated depending upon size and the intended use of the reclaimed area. If the size of rock fragments exceed 10 inches, the problems are more severe.

This guide does not cover all the soil features required in planning soil reconstruction, for example, slope, thickness of material, ease of excavation, potential slippage hazard, and soil moisture regime. Slope of the original soil may influence the method of stripping and stockpiling of reconstruction material but may have little effect on the final contour and therefore, on the stability and productivity of the reconstructed soil. Therefore, slope is not a criteria in this guide.

Thickness of material suitable for reconstruction and ease of excavation are important criteria in planning soil reconstruction operations. However, they are so dependent on the method of mining operations that they cannot be used as criteria in this guide. Potential slippage hazard is related to soil texture, slope, differential permeability between layers, rainfall, and other factors which are not included in the guide. Soil moisture regime climate and weather influence the kind of vegetation to plant and the rate of revegetative growth. They are not used as criteria because the relative ranking does not change with variable moisture regimes, that is, the best soil in a moist environment is the best soil in a dry environment. Furthermore, the soil may be irrigated to establish vegetation.

APPENDIX B.9.

SCS-USDA. 1974 - Soil Interpretations for Strip Mined Land in Mercer County, ND - Bismarck, ND.

SOIL INTERPRETATIONS FOR STRIP MINED LAND

Basic soils information is essential in obtaining satisfactory reclamation and restoration of lands disturbed by surface mines. Soil interpretations used in conjunction with the soil maps can indicate to planners, engineers and others the advisability of selecting, stockpiling and using specific soils as final cover for mined land.

Soil characteristics and interpretations significant to their use as final cover for mined land are given in the attached table. Soil characteristics or properties are estimated for representative soil profiles. These estimates are based on field observations made in the course of mapping, on test data for these and similar soils, and on experience with the same kinds of soil in other areas. The interpretations are based on the soil properties and on the experience of soil scientists, agronomists and engineers with these soils. Following are explanations of some of the columns.

Parent Material: The disintegrated and partly weathered rock from which soil was formed.

Natural Soil Drainage: Drainage that existed during the development of the soil as opposed to altered drainage or irrigation. Soil drainage, as a condition of the soil, refers to the frequency and duration of periods when the soil is free of saturation or partial saturation. Such conditions can be accurately measured, although the field scientist estimates them by inference. For class definitions, see Soil Survey Manual, pp. 169-172.

Depth of Rooting Zone: The depth of soil material that plant roots can penetrate readily to obtain water and plant nutrients. It is the depth to a layer that differs sufficiently from the overlying material in physical or chemical properties to prevent or seriously retard the growth of roots.

Available Water Capacity: The ability of soils to hold water for use by most plants. It is commonly defined as the difference between the amount of water in the soil at field capacity and the amount at the wilting point of most crops. The classes in the table are for a 60-inch soil profile and are as follows: Very low - 0-3"; Low - 3-6"; moderate - 6-9"; High - 9-12"; Very high - 12"+.

Permeability: That quality of a soil that enables it to transmit water or air. It is estimated on the basis of the soil characteristics observed in the field, particularly structure and porosity, and on the results of permeability and infiltration tests on undisturbed cores of similar soil material. The estimates do not take into account lateral seepage or such transient soil features as plowpans and surface crusts.

Erodibility: Susceptibility to erosion. Estimates based on the following criteria:

Low - All soils in subclass lle, level soils not subject to wind erosion, soils in class V, and soils in s or w subclasses with erosion hazard comparable to that of subclass lle soils.

Medium - All soils in subclass llle and soils in w or s subclasses with an erosion hazard comparable to that of subclass llle soils.

High - All soils except those that are coarse textured (lfs, ls, etc.) in subclass IVe and soils in s subclasses with a comparable erosion hazard.

Very High -All soils in VLe, Vllle, coarse textured soils in IVe, and soils in s subclasses with a comparable erosion hazard.

Where wind erosion is a hazard, it is specifically mentioned, e.g., severe wind erosion.

Inherent Fertility: Natural fertility of the soil based on the following criteria:

Low - Soils low in available P or K, or with pH below 5.0 in the A or upper B horizons, or soils having levels of salinity or alkalinity such that choice of plants or growth of plants is severely limited.

Medium - Soils intermediate between low and high in inherent fertility.

High - Soils high in available P and K, with ph of 5.5 or more in A and upper B horizons; levels of salinity or alkalinity are sufficiently low that choices or growth of plants are not limited.

Where salinity or alkalinity is a limitation, it is mentioned in this column.

Estimated Yields: Estimated yields under high level of management for commonly grown dryland crops. These estimates are based on information obtained from farmers and other agricultural workers in the area. They are averages for a period long enough to include years of both favorable and unfavorable temperatures and moisture supply during the growing season.

Degree of Limitation for and Soil Features Affecting Final Cover for Mined Land: The ratings in these columns indicate the thickness and general suitability of soil materials that might be used as final cover for areas of mined land. The total thickness available, in inches, including that from A, B, or C horizons is given in the first column. Relative suitability is shown in the second column. Only material that can serve as medium for plant growth is indicated and it is assumed that this material will be stockpiled and spread over leveled mine spoil.

Soil material given the rating good has physical, chemical, and biological characteristics favorable for growth of vegetation. Suitability is affected mainly by ease of working and spreading the soil material, as in preparing a seedbed; natural fertility of the material, or the resoonse of plants when fertilizer is applied; and absence of substances toxic to plants. Texture of the soil material and content of stone fragments are characteristics that also affect suitability. In the following table, each of these characteristics is rated as to degree of limitation affecting use. The soil property giving the highest degree of limitation is used to rate the soil material as good, fair, or poor.

Suitability Ratings of Soil Material for Use
as Final Cover for Areas of Mined Land

	Degree of Soil Suitability		
Items Affecting Use	Good	Fair	Poor
Moist consistence	Very friable, friable	Loose, firm	Very firm, extremely firm
Texture	fsl, vfsl, l, sil, sl	cl, scl, sicl	s, lfs, ls c & sic
Coarse fragments: percent, by volume	Less than 3 percent	3-15 percent	More than 15 percent
Sodium content	Not class determining if less than 15 percent exchangeable sodium		More than 15 percent exchangeable sodium is unsuitable
Soluble sales: conductivity of saturation extract	Less than 4 mmhos/cm	4-8 mmhos/cm	More than 8 mmhos/cm
Stoniness class 1/	0	1	2, 3, 4 & 5
Inherent fertility	High & Medium	Low	
Lime content	Low	Medium	High

1/ For class definitions, see Soil Survey Manual, pp. 216-223

APPENDIX B.10. WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY--LAND QUALITY DIVISION--GUIDELINE NO. 1 (1981).

GUIDELINES FOR TOPSOIL AND OVERBURDEN SUITABILITY FOR SURFACE COAL MINE RECLAMATION.

Criteria to establish suitability of topsoil (or topsoil substitutes).

Parameter	Suitable			Unsuitable
	Good	Fair	Poor	
pH	6.0 - 8.4	5.5 - 6.0 8.4 - 8.8	5.0 - 5.5 8.8 - 9.0	< 5.0 > 9.0
EC (Conductivity) mmhos/cm	0-4	4-8	8-16 > 8 may prove difficult to revegetate	> 16
Saturation Percentage	25-80		> 80 < 25	
Texture 1/	sl, l, sil, scl, vfsl, fsl	cl, sicl, sc ls, lfs	c, sic, s	
SAR	< 6	6-10	10 - 15 10 - 12 2/	> 15 > 12 2/
Selenium	< 2.0 ppm			> 2.0 ppm
Boron	< 5.0 ppm			> 5.0 ppm
Calcium Carbonate	0-15%	15-30%	over 30%	
Coarse Frag 3-10 in. (% vol) > 10 in.	0 - 15 0 - 3	15 - 25 3 - 7	25 - 35 7 - 10	> 35 > 10
Moist Consistency Dry Consistency	vfr, fr lo, so	lo, fi sh, h	vfi, exfi vh	

1/ SCS. 1978. National Soils Handbook, Notice 24.

2/ For fine textured soils (Clay >40%) (Gee et al., 1978).

APPENDIX B.10. (Cont.)

Parameters for determining fertility status of soil on reclaimed land surface. 1/

Parameter	Reported As	Recommended Procedure
1. Nitrate-Nitrogen	ppm	Extraction by ASA Mono. No. 9, Part 2, method 84-5.3.3, pg. 1216
2. Phosphorus	ppm	ASA Mono. No. 9, Part 2, method 73-4.4, pg. 1044-1047
3. Organic Matter	Percent	ASA Mono. No. 9, Part 2, method 90-3, pg. 1372-1376
4. Potassium	ppm	Ammonium acetate extraction, ASA Mono. No. 9, Part 2, method 71-3, pg. 1025-1027, and analysis by atomic absorption spectrophotometry or flame emission
5. pH	Hydrogen in activity at saturation (paste)	USDA Handbook 60, method (21a), pg. 102
6. Texture	USDA textural class	USDA Handbook 18, pg. 205-223
7. Particle Size Analysis	% clay, silt, sand and very fine sand (vfs=0.05-0.1 mm)	ASA Mono No. 9, Part 1, method 43-5, pg. 562-566

1/ Dates of sampling and analysis should be provided.

2/ Calcium:Magnesium Ratio may need to be determined in some instances.

APPENDIX B.10. (Cont.)

Criteria to establish overburden suitability,

Parameter	Surface (potential root zone)		Aquifer Restoration	
	Suitable	Unsuitable	Suitable	Unsuitable
pH	5.0-9.0	< 5.0 > 9.0	5.0-9.0	< 5.0 > 9.0
EC (Conductivity) mmhos/cm	< 8.0 1/	> 8.0		Depends on pre-mining water quality and overburden quality
Saturation Percentage	25-80	> 80 < 25		
Texture	< 50% clay < 85% sand	> 50% clay > 85% sand		
SAR	< 10	> 10 1/		depends on premining water quality and overburden quality
Selenium	< 2.0 ppm	> 2.0 ppm		depends on premining water quality and overburden quality
Boron	<5.0 ppm	> 5.0 ppm		depends on pre-mining water quality and overburden quality
Nitrate/ Nitrogen			<50 ppm	>50 ppm
Molybdenum	<1.0 ppm	> 1.0 ppm		
Copper 2/				
Lime	<30%	>30%		

APPENDIX B.10. (Cont.)

Parameter	Surface (potential root zone)		Aquifer Restoration	
	Suitable	Unsuitable	Suitable	Unsuitable
Acid-base Pot. 3/	>-5 tons $CaCO_3$ equivalent/1000 tons	<-5 tons $CaCO_3$ equivalent/1000 tons		<-5 tons $CaCO_3$ equivalent/1000 tons
Lead	<10 ppm	>10 ppm		depends on pre-mining water quality and over-burden quality
Arsenic	<2.0 ppm	>2.0 ppm		depends on pre-mining water quality and over-burden quality

1/ Overburden material placed directly under respread topsoil should be of similar suitability as the topsoil. The upward migration of soluble salts must be considered.

2/ An excessive consumption of molybdenum through ingestion of vegetation may be toxic to animals. The concern is directly related to the Cu:Mo ratio in the plant tissue.

3/ Record as Acid pot. in meq H^+/100 g, Neutralization pot., acid-base potential in ± tons $CaCO_3$ equivalent/1000 tons.

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REVIEW, EVALUATION AND RECOMMENDATIONS FOR PREMINE VEGETATION INVENTORIES IN MONTANA, WYOMING, COLORADO AND NORTH DAKOTA

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INTRODUCTION

This paper reviews the State and Federal laws and regulations that pertain to premine vegetation inventories in Montana, Wyoming, Colorado, and North Dakota, evaluates the most common requirements, recommends some improvements, and presents a case study.

The origin of the laws governing premine vegetation inventories is both political and scientific. The laws are political--they represent a consentaneous view that areas disturbed for coal mining must be permanently revegetated, enforceable standards are necessary to evaluate revegetation success, and premine vegetation best serves as the standard by which revegetation success can be measured. Regulations are scientific--they identify the vegetational attributes and plant ecological methods which are appropriate for making these evaluations.

It might be argued that: these laws and regulations are punitive and discriminatory; farmers, ranchers and other landowners or developers cause significant disruptions over much larger areas with little or no regulation, premine inventories are of marginal utility for revegetation planning, and the cost incurred is not justified by their utility. However, these allegations require a political solution and are not discussed here.

On the other hand, one may ask why the millions of dollars spent on premine vegetation inventories have resulted in such minor contributions to an understanding of the vegetation studied or to the field of plant ecology. It is true that premine vegetation inventories are funded and performed to obtain mining permits, but the lack of further contributions remains noteworthy. Some of the reason lies in the selection of faulty or inappropriate permitting requirements and methods, but to a greater degree, the limitations arise from a lack of study of plant communities, the collection of junk data, which is not the inherent result of the method employed, and "data analysis" which does not go beyond statistical data summarization. This paper points out some areas where improvements are possible.

PART I. REVIEW OF LAWS, RULES, REGULATIONS, AND GUIDELINES

Federal

The Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87, August 3, 1977) created the Office of Surface Mining Reclamation and Enforcement (OSM) within the Department of the Interior. The OSM regulations are preeminent because the OSM was granted authority to approve or disapprove State programs for controlling surface coal mining operation and reclaiming abandoned mine lands. Three of the purposes of this law were to: (1) prevent surface mining in areas where reclamation was unfeasible (Sec. 102 (c)), (2) assure reclamation soon after mining (Sec. 102 (e)), and (3) protect the environment (Sec. 102 (a)), (d)).

The Act sets requirements for reclamation plans, including:

> Sec. 508. (a): Each reclamation plan submitted as part of a permit application pursuant to any approved State program or a Federal program under the provisions of this Act shall include, in the degree of detail necessary to demonstrate that reclamation required by the State or Federal program can be accomplished, a statement of:
>
> Sec. 508. (a) (2) (c): The productivity of the land prior to mining, including appropriate classification as prime farm lands, as well as the average yield of food, fiber, forage, or wood products from such lands obtained under high levels of management;

The mine operator must comply with the environmental protection performance standards of the Act, for which modifications are presently being considered.

> Sec. 515 (b) (19): Establish on the regraded areas, and all other lands affected, a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area; except, that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved postmining land use plan;

Revegetation is later addressed in Rules and Regulations (Federal Register, Thursday, December 13, 1977).

> S715.20 (a) General. (1) The permittee shall establish on all land that has been disturbed, a diverse effective, and permanent vegetative cover of species native to the area of disturbed land or species that will support the planned postmining uses of the land approved according to S715.13. For areas designated as prime farmland, the reclamation procedures of S716.7 shall apply.
>
> (2) Revegetation shall be carried out in a manner that encourages a prompt vegetative cover and recovery of productivity levels compatible with approved land uses. The vegetative cover shall be capable of stabilizing the soil surface with respect to erosion. All disturbed lands, except water areas and surface areas of roads that are approved as a part of the postmining land use, shall be seeded or planted to achieve a vegetative cover of the same seasonal variety native to the area of disturbed land. If both the pre- and postmining land use is intensive agriculture, planting of the crops normally grown will meet the requirement. Vegetative cover will be considered of

the same seasonal variety when it consists of a mixture of species of equal or superior utility for the intended land use when compared with the utility of naturally occurring vegetation during each season of the year.

715.20 (e) Methods of revegetation. (4) Where wildlife habitat is to be included in the postmining land use, the permittee shall consult with appropriate State and Federal wildlife and land management agencies and shall select those species that will fulfill the needs of wildlife, including food, water, cover, and space. Plant groupings and water resources shall be spaced and distributed to fulfill the requirements of wildlife.

715.20 (f) Standards for measuring success of revegetation. (1) Success of revegetation shall be measured on the basis of reference areas approved by the regulatory authority. Reference areas mean land units of varying size and shape identified and maintained under appropriate management for the purpose of measuring ground cover, productivity and species diversity that are produced naturally. The reference areas must be representative of geology, soils, slope, aspect, and vegetation in the permit area. Management of the reference area shall be comparable to that which will be required for the approved postmining land-use of the area to be mined. The regulatory authority shall approve the estimating techniques that will be used to determine the degree of success in the revegetated area.

(2) The ground cover of living plants on the revegetated area shall be equal to the ground cover of living plants of the approved reference area for a minimum of two growing seasons. The ground cover shall not be considered equal if it is less than 90 percent of the ground cover of the reference area for any significant portion of the mined area. Exceptions may be authorized by the regulatory authority for--

(i) Previously mined areas that were not reclaimed to the standards required by this chapter prior to the effective date of these regulations. The ground cover of living plants for such areas shall not be less than required to control erosion, and in no case less than that existing before redisturbance;

(ii) Areas to be developed immediately for industrial or residential use. The ground cover of living plants shall not be less than required to control erosion. As used in this paragraph, immediately means less than 2 years after regrading has been completed for the area to be used; and

> (iii) Areas to be used for agricultural cropland purposes. Success in revegetation of cropland shall be determined on the basis of crop production from the mined area compared to the reference area. Crop production from the mined area shall be equal to that of the approved reference area for a minimum of two growing seasons. Production shall not be considered equal if it is less than 90 percent of the production of the reference area for any significant portion of the mined area.
>
> (3) Species diversity, distribution, seasonal variety, and vigor shall be evaluated on the basis of the results which could reasonably be expected using the methods of revegetation approved under paragraph (e) of this section.

Montana

The basic law governing coal mining in Montana is "The Montana Strip and Underground Mine Reclamation Act" (Title 82, Chapter 4, Montana Code Annotated), administered by the Montana Department of State Lands. Revegetation is a defined part of reclamation. This Act requires (84-4-222 (2), (1), MCA)

> ...a listing of plant varieties encountered in the area to be affected and their relative dominance in the area, together with an enumeration of the tree varieties and the approximate number of each variety occurring per acre on the area to be affected, and the locations generally of the various kinds and varieties of plants, including but not limited to grasses, shrubs, legumes, forbs, and trees."

A permit may be refused (84-4-227, (2), MCA) if the (proposed) affected area has

> ..."special, exceptional, critical, or unique characteristics," including biological productivity or ecological fragility or functional importance. Revegetation calls for a "diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in cover to the natural vegetation of the area...."

This vegetation must support livestock and wildlife similarly to the premine vegetation, regenerate under natural conditions, and prevent soil erosion to the extent achieved prior to mining.

When certain conditions are met, the affected area may be reclaimed to cereal crop species or other uses, but this is not related to the topic of this paper.

Montana's Permanent Program, Strip and Underground Mine Reclamation Rules and Regulations, pursuant to the Strip and Underground Mine Reclamation Act, contain a plethora of regulations in their 385 pages, some of which concern premine vegetation inventories either directly or indirectly. Premining requirements include a vegetation map at a scale of 1:4,800 which delineates community types on the basis of two or more functionally dominant species, a narrative description of community types including associated species and important environmental factors, and a range site map and discussion of trend and condition. The location and boundaries of reference areas* must also be mapped.

For operations encompassing over 100 acres, revegetation success is determined by comparison with unmined reference areas; at least one reference community is needed for each premine community. When possible, these reference areas should be in good or excellent range condition under the SCS system, and they should be grazed at 50 percent or less utilization.

Reference area and premine vegetation are to be compared for production, canopy-coverage, season of use, and toxic content, with additional measurements and comparisons for communities containing woody species. Weighted calculations of production, canopy-coverage, and diversity are obtained by using simple formulae, which are given. These calculations make use of data from reference areas and the premining acreages of communities. Production and canopy-coverage data are stratified by the following morphological classes: annual grasses; perennial grasses; annual, biennial, and perennial forbs; and shrubs. Diversity is defined by the number of species occupying 1 percent or more of ground cover.

Density measurements are required for woody species; definition of what constitutes an individual plant for density measurement purposes is given. For woody species, information is required on site quality, stand size, stand condition, site and species relationships, and utilization.

In 1980, the Montana Department of State Lands issued and solicited comments on some draft vegetation guidelines, which have not been modified or made final since then. Preliminary vegetation mapping is recommended on a physiognomic basis. A system of nested samples for premine sampling is recommended, with the number of plots in proportion to community size. It is suggested that a "complete species list, for each community type, may be obtained by monthly observation," presumably in a single year. The adequacy of the number of coverage samples is to be evaluated by constructing a species curve. For production, at least 30 one-half-square-mile plots per community are suggested. Site indices for tree species are to be calculated, apparently on the basis of random sampling of individuals.

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*"Reference area" is defined in Montana as "a unit of land maintained under approved management for the purpose of measuring vegetation, ground cover, productivity and plant species diversity that is produced naturally or by crop production methods approved by the department. Reference areas must be representative of geology, soil, slope, and vegetation in the permit area as determined by the premining inventory." This definition will serve for other States except Wyoming.

Wyoming

The Wyoming Environmental Quality Act of 1973 provides the basis for reclamation law in Wyoming. The Wyoming Environmental Quality Council and Administrator of the Land Quality Division, Department of Environmental Quality, adopted Rules and Regulations to implement this Act. In 1981, the Wyoming Department of Environmental Quality, Land Quality Division, issued Guideline No. 2 pertaining to application for Permit to Mine and bond release criteria. Compliance with this guideline is not mandatory and other approaches may be acceptable. The guideline does, however, outline an "acceptable" approach to meeting the vegetation requirements for permitting (complete with formulae) and as such will be addressed here.

The Wyoming Environmental Quality Act establishes reclamation standards, which include reclaiming and revegetating to assure the highest previous use of affected lands. Applications to mine must include a mining plan and reclamation plan which address mining impacts and identify the proposed future use(s) of the affected area and also the type of vegetation.

The Rules and Regulations contain some rather general criteria for vegetation inventories, including identifying threatened or endangered species and incorporating Federal requirements already discussed. The requirements for bond release indirectly address the application of premine inventories. The following quote is from Chapter 4, Sec. 2, of the Environmental Protection Performance Standards:

> (d) (6) The administrator shall not release the entire bond of any operator until such time as revegetation is completed if revegetation is the method of reclamation as specified in the operator's approved reclamation plan. Revegetation shall be deemed to be complete when: (1) the vegetation cover of the affected land is shown to be capable of renewing itself under natural conditions prevailing at the site, and is at least equal to the cover on the area before mining, (2) the productivity is at least equal to the productivity on the area before mining, (3) the species diversity and composition are suitable for the approved postmining land use and the revegetation area is capable of withstanding grazing pressure at least comparable to that which the land could have sustained prior to mining, unless Federal, State or local regulations prohibit grazing on such lands, and (4) the requirements in (1), (2) and (3) are met for the last 2 consecutive years of the bonding period. The administrator shall specify methods for determining whether equal cover or productivity has been established. Control areas* that will not be affected by mining activities shall be

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*According to the Rules and Regulations, "control area" means an area of at least two acres which will not be disturbed by mining activities and which is used to adjust the vegetation data for climatic differences between sample years.

established in each vegetation type or range site that is representative of the area that will be affected. Control areas shall be sampled for vegetative cover, productivity, and species diversity in the same season that the area to be affected is sampled for baseline data.

They shall be sampled when determining if revegetation has been accomplished according to the provisions above. Control areas will function as an adjustment factor for any difference in results between different sample years. Where premining cover, productivity and species diversity data cannot be collected, reference areas** shall be established which will be representative of the premining vegetative conditions. Reference areas shall be sampled by methods acceptable to the administrator to determine if revegetation has been accomplished according to the provisions of this paragraph. The administrator may authorize alternative procedures for the requirements of this paragraph for determining the success of vegetation where small incidental acreages of disturbances are involved.

(a) If reforestation for commercial harvest is the method of revegetation, reforestation shall be deemed to be complete when a reasonable population density as established in the reclamation plan has been achieved, and plants have shown themselves capable of continued growth for a minimum period of five (5) years following planting, and the understory vegetation is adequate to control erosion and is appropriate for the land use goal. Quality and quantity, vegetation cover, productivity, and species diversity shall be determined in accordance with scientifically acceptable sampling procedures approved by the administrator.

(b) When the approved reclamation plan is to return to cropland, reclamation shall be deemed to be complete when productive capability is equivalent, for at least two consecutive crop years, to the premining conditions or approved reference areas. The premining production data for the reclaimed site shall be considered in judging completeness of reclamation whenever said data are available.

**According to the Rules and Regulations, "reference area" means a land unit maintained under appropriate management for the purpose of measuring vegetation, ground cover, production, and plant species diversity. Reference areas must be representative of the geology, soil, slope, and vegetation in the permit area.

Guideline No. 2 contains 17 pages of rather detailed vegetation guidelines which are briefly summarized here. The major topics are as follows:

Mapping

Vegetation types or range sites of the entire permit area should be mapped at a scale of 1:4,800 to 1:8,400. Transect or quadrat locations and control areas should be indicated.

Description of Mapping Units

Vegetation types or range sites should be described by the dominant vegetation and site factors such that boundaries can be "located with reasonable repeatability by independent observers."

Plant Species List

A plant species list should be compiled for the area with emphasis on threatened or endangered species and new State records or range extensions.

Quantitative Measurements in Affected and Control Areas

Mapping units should be sampled in the affected and control areas for cover, herbaceous productivity, and tree and shrub density. Sampling procedures are addressed in some detail. Criteria for bond release are explained.

Colorado

The Colorado Mined Land Reclamation Act (Article 32 of Title 34, C.R.S. 1973, as amended--1976 Session Law, H.B. 1065) specifies that applicants for permit must prepare a vegetation map for the affected area. Reclamation requirements depend upon the postmining land use, but (Sec. 34-32-116 (F)) "In those areas where revegetation is part of the reclamation plan, land shall be revegetated in such a way as to establish a diverse, effective, and long-lasting vegetative cover that is capable of self-regeneration and at least equal in extent of cover to the natural vegetation of the surrounding area...."

The Rules and Regulations of the Colorado Mined Land Reclamation Board require a vegetation map which delineates plant communities on the basis of visually dominant species. Plant communities must be described in terms of species composition, cover, and productivity. The environmental factors controlling or limiting the distribution of species should be discussed. No vegetation type may be disturbed until adequate data are obtained.

Reference areas must be provided for each community, and the similarity of reference areas and affected areas must be statistically evaluated with respect to herbaceous cover and productivity, species diversity, and woody shrub density. Crop yield must be evaluated if appropriate. Revegetation is to be aimed at attaining vegetation cover and production levels compatible with the postmining land use.

Revegetation success is based on the statistical comparison of reference area vegetation and revegetated communities with respect to cover, production, species diversity, and woody plant density. Comparison may be made on a one-to-one, community-to-reference-area basis, or on a weighted basis whereby data from reference areas are combined and compared with a reduced number of reclaimed communities. Cropland is evaluated on the basis of statistical comparison of crop production.

North Dakota

The North Dakota Century Code (38-14.1-14) states that permit applications include characteristics of "vegetation cover" and premine productivity. Regulations (69-05.2) specify more detailed requirements.

A map at a scale of 1:4,800 is required showing range sites and condition classes for rangeland and "vegetation types" for woodlands and fish and wildlife habitat. A species list must be compiled and production estimated for most nonwoody vegetation (often by soil mapping unit), with density and cover data required for woody vegetation.

Reference areas serve as revegetation standards in some cases. The adequacy and suitability of reference areas must be demonstrated. Measurement techniques are not specified but must be approved by the North Dakota Public Service Commission. To be successful, the following conditions must be met during the last 2 years of the performance bond period:

1. Rangeland, Hayland, Pastureland. Cover and production equal to or greater than the standard (usually reference area) at 90 percent confidence level for herbaceous vegetation; 80 percent confidence level for woody vegetation.

2. Cropland. Crop production equal to or greater than the standard at 90 percent confidence level.

3. Woodland, Fish and Wildlife Habitat. Revegetation species chosen to fulfill wildlife needs. Density of woody species equal to or greater than standard at 80 percent confidence level (individual plant definitions are given). Ground cover equal to or greater than 70 percent of the standard at 90 percent confidence level and must control erosion. Species diversity, seasonality, and regeneration capacity must be incorporated in the evaluation.

SUMMARY

The reclamation regulations reviewed here generally aim at assuring that mined areas are revegetated (when vegetation is a principal of postmining land use) such that ecosystem function is maintained without excessive site deterioration or environmental degradation. The revegetated areas should be capable of serving as rangeland, cultivated land, wildlife habitat, forest, etc., whichever is appropriate. In most cases, the appropriate revegetation criteria are based upon the premining vegetation or land use. Because the premining vegetation is destroyed, communities outside the affected area are chosen to represent the destroyed vegetation; these communities provide the standards against which revegetated areas are compared. This is the reference area concept. Reference areas are chosen on the basis of similarities to premine vegetation, soils, slope, geology, and aspect. Production, cover, species diversity, and woody plant density have generally been identified as the important vegetation parameters which are useful to assess vegetation success. Vegetation or range site maps and plant species lists for the affected area are often required, and in some cases the seasonality of plant species must be specified. Table 1 summarizes some premine vegetation inventory requirements.

TABLE 1. SUMMARY OF PREMINE VEGETATION INVENTORY REQUIREMENTS*

	Reference areas	Vegetation or range site map	Production	Cover	Species diversity	Woody plant density	Seasonality	Identification of communities of special concern	Plant species list	Community analysis and classification
Federal	+	-**	+	+	+	+	+	-	-	-
Montana	+	+	+	+	+	+	+	+	+	-
Wyoming	+***	+	+	+	+	+	-	-	+	-
Colorado	+	+	+	+	+	+	-	-	-	-
North Dakota	+	+	+	+	+	+	-	-	+	-

*In the case of Wyoming, some indicated areas of study are not strictly required.

**May be requested.

***Or Control Areas in Wyoming.

PART II. EVALUATION

The review of mining laws, regulations, and guidelines (Part I) reveals a consensus that the following vegetation topics are important for premine vegetation inventories: Vegetation mapping, community production, vegetative cover, diversity, woody plant density, species list, and reference areas.

In the first part of this section, the appropriateness of these topics for premine inventories and ultimate use in vegetation determinations are discussed. The potential for these studies to contribute beyond impact and reclamation assessment is also addressed. However, while the choice of estimation methods has a bearing on the degree to which a study may find further application, other factors, such as the importance of the matter being investigated and the quality of study design and execution, are at least as important. Later in this section, some technical considerations for mapping, measurements, and calculations are discussed in more detail.

The goal of revegetation is largely functional: Community function, land use, and site conservation similar to premine levels. Premine vegetation requirements are largely descriptive, with the notable exception of production data. From the standpoint of utility, a shift to more functional evaluations is highly desirable, and this topic is briefly addressed in Part III. A major reevaluation such as this is unlikely at this stage due to bureaucratic and legislative inertia and a strong reluctance to make changes which imply that previous standards were not the best and most suitable ones. For this reason, the following evaluation concentrates on existing requirements.

Utility Of Premine Vegetation Inventory Requirements

Vegetation Mapping

Effective postmining revegetation can be accomplished without vegetation mapping and indeed without any but the most cursory premine vegetation inventory. However, the question of how to evaluate the success of revegetation becomes problematic in the absence of a specified method of assessment and comparison, such as the reference area approach. Premine vegetation mapping may be useful for reclamation assessment purposes, although there is also a potential for introducing oversimplifications into the vegetation analysis.

A vegetation map provides the basis for areal determination of the communities or community types involved. After appropriate data on production, cover, etc., are collected for communities, the vegetation map provides the basis for calculating the contribution of each community (or community type) in terms of the total affected area. A vegetation map may also be useful for wildlife habitat evaluation.

While not related directly to permitting, a properly prepared vegetation map assures that someone (presumably qualified) has studied the vegetation of the proposed mine area in great detail, has become intimately acquainted with the vegetation, and has grappled with the questions of what constitutes a stand or community type and how much variation in species composition within the mapping units is allowable, how boundaries can be recognized and characterized, and so on. In short, vegetation mapping can assure that the vegetation was studied, not merely sampled.

Vegetation mapping can be one of the most difficult endeavors in descriptive plant ecology, depending upon the complexity of the vegetation. In natural or seminatural vegetation, attempting to portray the actual vegetation of a square mile on a piece of paper 13.2 inches square (1:4,800) can be done only with a great deal of information loss, and it is the responsibility of the vegetation mapper to maximize fidelity to the actual vegetation. While the methods of production and cover estimation are often specified in great detail, regulatory agencies do not specify methods for vegetation classification or mapping, which has resulted in vegetation maps of varying quality and usefulness.

Premining vegetation maps have been of little use beyond reclamation purposes. It is true that they may be illustrative of community patterns and environmental relationships, but they are seldom used for these purposes and the relationship of communities to environmental factors can be obtained more directly--for example, by nonparametric statistical analysis or discriminant analysis.

Production

Production has a legitimate place in premine inventories and revegetation evaluation. Whittaker (1975) suggests that production seems to be the most significant single attribute of a community. Production estimation is useful for both descriptive and functional investigations of vegetation. The preeminence of production among plant community measurements is attested to by the fact that ecologists have chosen production estimation for research over many decades, while more faddish measurements have come and gone or received limited application.

Production or productivity* data supply a more complete means for assessing the abundance and also functional contribution of community dominants than other fundamental measurements, such as density. Production estimates are generally more reliable and less affected by a change in personnel than cover estimates.

The popularity of production estimates facilitates comparisons between various research efforts, although methods must be similar. To the layman, the importance of production lies in its utility (AUMs, yield, etc.), which is self-evident.

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*The terms "production" and "productivity" are used synonymously in this paper, but productivity refers to the rate at which dry matter, measured by weight or mass, is produced per unit area. Production may refer to productivity or to biomass or standing crop, concepts perhaps better described by those more explicit terms.

Among the negative points for production estimation are the high cost, the (usually) destructive sampling (which does not allow comparisons of the same plots through time), failure to account for materials transported to unsampled tissues, and the differential response of tissues to drying. Insect infestation can destroy the validity of data. Some technical considerations for production estimation are discussed later in this section.

The usefulness of production data beyond reclamation purposes depends upon the quality of the data, the areal extent of the community type being studied, and whether or not the production data are correlated with separately measured environmental factors, most notably moisture balance.

Cover

Cover estimates* are appropriate at several stages of premining inventories and revegetation assessment. These include vegetation reconnaissance and community comparisons. For descriptive plant ecology, cover estimation has the following advantages:

1. Cover can be quickly estimated relative to production, and in some cases even relative to density.
2. Cover data are easily collected for each plant species present in a sample--even at very low abundance levels--and may be collected for mosses, lichen, etc.
3. Cover data may be collected for standing dead, litter, bare ground, rock, and other nonvegetative classes.
4. Cover estimates are appropriate for derived values representing similarity, species diversity, etc.
5. Cover estimation is appropriate (to a varying degree) for a variety of life-forms.
6. The reviewer of cover data can form a more realistic mental image of the sampled community than is afforded by most other types of data.
7. The same frames may be sampled repeatedly through time, which greatly facilitates comparison.
8. Cover data may be useful for habitat evaluation, vegetation classification, and other uses beyond revegetation.

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*Various concepts and methods for estimating cover are discussed later in this section.

The chief disadvantage for cover data is not inherent but stems from the fact that cover estimation techniques are often misapplied by careless or improperly trained investigators. Thus, when the data seem to indicate surprising conclusions or anomalies, the data may be suspect. However, properly trained and conscientious personnel may attain a high degree of agreement in cover estimation. Other problems with cover estimation are discussed later in this section.

The utility of cover data beyond premine inventories depends upon the use to which they are put. If premining and postmining study includes detailed phytocenological investigation and classification, the effects of climate on cover, comparison of cover and production, the relationship between cover and erosion, etc., then the data may be quite useful in other investigations.

Diversity

Many reclamation laws call for a "diverse cover" of vegetation. The term "diverse cover" is vague and subject to many interpretations. It may refer to a diversity of species in a community, a diversity of species of differing seasonalities in a community, or perhaps a diversity of life-forms or structural diversity in a community. "Diverse cover" can also refer to a diversity of communities in the landscape, such as that often found in natural or seminatural vegetation.

For reclamation purposes, "diverse cover" has generally been equated with "species diversity," another term that suffers from lack of a precise definition. At the time when most reclamation regulations were being drafted, there was a common belief that complex communities were more "stable" than simple communities. Stability referred to community inertia, resiliency, recoverability, and in general the ability of a community to withstand or adapt to stress or disturbance while minimizing ecosystem disruption and site degradation. Complexity referred to diversity of food webs or trophic structure and later to species-abundance relations.

At first glance a correlation between diversity and stability seemed to be intuitively true, and thinking was guided by crude analogies to machinery (spare parts), the susceptibility of manmade monoculture to pest outbreaks, and the general increase in species diversity from Arctic or alpine communities (low diversity, fragile) to tropical rain forests (high diversity, stable). It has since been pointed out (even assuming the analogy is apropos) that complex machinery is often more subject to breakdown than simple machinery, that tropical rain forests, while they may appear stable, are among the more fragile communities, and that in any case a correlation between diversity and "stability" may not be indicative of a causal relationship. Other factors, such as the magnitude of environmental fluctuations and the adaptiveness of the dominant species, may be more important.

The notion that species diversity denotes "stability" is at best questionable, and certainly it is not true in all cases. This topic is discussed in more detail later in this section, but the permanence or adaptiveness of revegetated communities can be more directly evaluated by monitoring through a sufficiently long bonding period. Most species diversity indices denote species-abundance relations, but their functional implications are largely unproven.

The use of species diversity indices has made possible one of the non sequiturs of revegetation requirements--weighted diversity comparisons, in which the numerical values representing species diversity for two or more communities are weighted on the basis of the areal extent of these communities and averaged. A single revegetated community may be compared with this weighted average. This approach is not only rooted in a false view of species as equivalent and interchangeable units but confounds more reasonable interpretations of diversity.

In contrast, a diversity of life-forms or seasonalities within communities or a diversity of communities in a landscape may be justified in revegetation requirements--e.g., to provide a diversity of habitats for wildlife, aesthetic diversity, a source of propagules, etc. With the exception of some seasonality requirements, this is not directly addressed by reclamation rules, regulations or guidelines, and reliance upon species diversity indices tends to detract from such interpretations of diversity.

The various indices used to assess species abundance relationships can be useful for comparative purposes and to investigate what they indicate in terms of community function. As with cover data, the usefulness of investigating species abundance relations depends upon overall study design and quality.

Woody Plant Density

The requirement for density comparisons in the evaluation of revegetation success involving woody species (sub-shrubs, shrubs, trees) stems from the slow growing, long-lived nature of some woody species relative to the length of the performance bond period. Woody plant densities comparable to those in premine or reference areas may not yield comparable cover or production values during the bond period but may result in comparable abundance some time after the bond period. Conversely, if woody plant production or cover were comparable at the end of the bond period, overabundance and crowding might be attained in subsequent years.

This consideration ignores the more fundamental question of if, or in what circumstances, comparable woody plant abundance is desirable. Density requirements for certain shrubs (e.g., big sagebrush, rabbitbrush, broom snakeweed) point out one of the more glaring discriminations of reclamation requirements. On hundreds of thousands of acres of rangeland, reduction of many common shrub species has been accomplished by mechanical or chemical means or by burning in the name of range improvement with the goal of increased yield of more palatable species. Additional hundreds of thousands of acres of shrublands--including riparian areas and alluvial valleys--have been converted to cropland. Both practices continue, and in general society approves these activities. Yet revegetation to shrublands may be required for bond release.

It seems reasonable to expect that revegetation to shrublands has a purpose beyond the fact that the premine vegetation (or a portion thereof) was shrubland. When this is demonstrated, as it may well be in the case of critical wildlife habitat or a needed diversity of communities, then density measurements are useful for making comparisons and evaluating revegetation success. However, as an inflexible requirement, shrubland revegetation may run counter to other goals, such as increased forage yield, and the effort entailed might better be redirected.

Plant Species List

A plant species list for the affected area is often required. These lists are not used for revegetation assessment and are only marginally useful for impact assessment prior to mining.

The requirement for plant species lists is probably related to the Federal requirement that threatened or endangered species be identified and preserved. Unless the flora of the area is catalogued, it is unlikely that any rare, threatened, or endangered species would be identified. However, the goal of preserving threatened or endangered species is often difficult to achieve.

The meaning of "rare, threatened, or endangered" is not self-evident nor even generally agreed upon. Identification of such species often seems to be dependent upon the amount of study an area has received and the number of botanists familiar with the flora of that area who are on the committee compiling the list. Reasons for protecting such species (usually couched in utilitarian terms) are often less than compelling, and society as a whole seems unprepared to declare that all species have a right to exist. Finally, plant species lists are usually subject to annual revision, particularly in areas of climatic fluctuation, and it is questionable that a complete list will result from a single or even several years of study.

Perhaps the best result of the species list requirement is that someone (presumably) examines the flora of the affected area in detail, identifies any unusual findings, and makes this information available for more informed impact assessment and decisionmaking. It is not clear whether species lists are actually of much consequence for this purpose, and in rare cases where the issue has been clearly identified (snail darters and louse warts), the projects endangering the species were approved. Compilation of species lists sometimes provides new information about the geographic range of species.

Reference Areas

There are two possible approaches--baseline and reference area--that allow the premine vegetation which will be destroyed or disturbed to serve as the standard for revegetation evaluation. In the baseline approach, plant communities are monitored with respect to selected vegetation parameters over a period of years; during this time, data are also collected on those independent variables thought to affect vegetation parameters. When these relationships are quantified (probably by regression formulae) in a manner that accounts for an acceptably high amount of the observed variance in vegetation parameters, the baseline period may be considered over. For example, Smoliak (1956) was able to account for a large amount of the variations in production using precipitation data. Revegetation success is judged by comparing parameter estimates from the revegetated communities to the values which would have been expected by plugging current data for the independent variables into the formulae derived during the baseline period.

In the reference area approach, communities outside the affected area are chosen to serve as surrogates for communities within the permit area. Revegetated communities are sampled simultaneously with the reference communities and comparisons are made directly, since it is assumed that climatic condition and management for the paired communities are equivalent.

Reference Areas

	Advantages	Disadvantages
Baseline Approach	1. Affected communities are standards.	1. Several years of study minimum.
	2. Better understanding of functional ecology.	2. Possible failure to quantify relationship adequately.
	3. Findings applicable to range management, etc.	3. Quantified relationships may hold over only a restricted range of conditions.
		4. Cannot incorporate new environmental conditions (e.g., pollution) or those not measured during baseline period (e.g., grasshoppers).
Reference Area Approach	1. Possible to select reference areas soon after classification, mapping, etc.	1. Surrogate communities are standards.
	2. Incorporates all environmental effects on vegetation.	2. Potential for improper choice of reference areas or abuse of these areas.

The reference area approach is best for comparing premining and revegetated communities. In most cases, the delay entailed by years of data collection necessitated by the baseline approach is sufficient to rule it out as an alternative unless adequate existing data are available. However, the baseline approach is far more likely to contribute to an understanding of community/environment relationships.

Technical Considerations for Premine Vegetation Inventories

Maps

Vegetation Maps

The reference area approach requires a vegetation map for areal determinations of community types. The map should portray actual vegetation rather than potential or climax vegetation because subsequent study centers on the existing vegetation. Identifying potential vegetation involves speculation, and direct vegetation comparisons are needed for reference area selection and revegetation assessment.

A vegetation map implies a classification and may be regarded as a cartographic expression of a classification (Kuchler 1967). The usefulness and fidelity of a vegetation map are dependent in part upon the underlying classification scheme*; nevertheless, there is very little (sometimes no) attention paid to reconnaissance or classificatory procedures in rules, regulations, or guidelines. The subject of phytocenology** or phytosociology is never mentioned. This omission would be fitting if very broadly defined mapping units were appropriate or if gradients were always abrupt and communities homogeneous, which is not the case. The subject of classification is considered in Part III, and we will assume for this discussion of mapping that a suitable classification is available.

The classification and map scale dictate the detail possible in the vegetation map. A classification which identifies a single big sagebrush/mixed grass type clearly offers less potential for detailed vegetation mapping than a classification which identifies three big sagebrush types, each with different characteristic understory species. The usual scale of 1:4,800 offers the potential for some rather fine distinctions, but at the same time, the vegetation of a square mile can be portrayed on a piece of paper 13.2 inches square only with a great deal of information loss. It is often necessary to list several community types for a single mapping unit because of scale limitations or because of a complex vegetation mosaic. Some inclusions to mapping units will almost certainly occur.

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*It might be argued that classification is not necessary when communities rather than community types are mapped, and each community is taken to be unique. However, this is tantamount to saying that vegetation can be portrayed in an orderly manner without any referential framework. In fact, the same problems must be overcome, albeit in a universe devoid of references. These problems include recognizing and delimiting communities and coenclines, drawing lines where there are none, determining the compositional variability allowable within a community, deciding what criteria will be used to differentiate communities, and so on.

**See footnote under Phytocenology and Classification section.

Vegetation mapping is problematic almost by definition. The vegetation of any area is unique and heterogeneity is relative. Environmental and community gradients are common and species (even ecotypes) are individualistic in their tolerance to both physical and biotic factors. In a detailed classification, not every community sampled will eventually be assigned to a community type, and similarly not every community in the mapped area can rightly be designated as a classificatory unit.

Vegetation mapping is ultimately a subjective endeavor, but this does not mean that vegetation mapping is without an understandable basis. The vegetation may be examined systematically at intervals suitable for the map scale, and the communities encountered examined and compared with the classification. Useful adjuncts to classification for this purpose are average abundance (often cover) and constancy tables, which identify each species encountered in communities that were incorporated into community types and specify the average abundance of these species and the percentage of sample stands in which they were present. Some phytocenological methods, such as ordination or cluster analysis, may indicate communities which are transitional (as portrayed in the ordination, cluster analysis, etc.) between community types, and similar communities may be indicative of coenclines.

The vegetation mapper must decide then whether the vegetation he is examining can be described well by a community type designation, whether it is a community differing in some fundamental respect from identified community types, or whether it is a coencline. Communities not served by the classification can be mapped as departures from community types when similarities remain strong, but when highly dissimilar, the community must be described on the same basis as community types. Species abbreviations and abundance symbols are often suitable for mapping in either case.

Narrow coenclines can be ignored, as when the line on the map separating mapping units roughly represents the actual width of the transitional zone at the map scale. Larger coenclines should be mapped as such. In one approach, the map may have no lines separating types, but rather the symbols representing types should grade into one another much as the communities themselves. In another approach, boundaries may be indicated by broken lines or symbols suggestive of the interpretation of communities. However, these methods are not well suited to the reference area approach, for it may not be valid to consider the transitional areas as an average of two communities, but as something different. Alternatively, coenclines of consequential extent may be mapped (more or less arbitrarily) and represented by reference communities.

Crops are usually best mapped as "cultivated areas" rather than named for the crop species because of the vegetational instability of these areas--i.e., what was a wheat field in the year of mapping might be fallow the following year and planted to alfalfa the next year. Mapping by crop species can thus lead to confusion in some cases, though it may be appropriate when crop consistency exists.

To the extent possible, vegetation mapping should be done in the field, as it is unlikely that mapping problems can be better resolved elsewhere at a later date. Mapping should be done at the final mapping scale or a scale allowing greater resolution. Mapping may be done on overlays to other information sources, such as aerial photographs or topographic maps.

Aerial photographs can be especially useful for mapping the more visible elements, such as tree or shrub distribution or areas of low foliar cover. In some cases, differences noticeable on the ground are not visible on aerial photographs; conversely, aerial photographs may seem to reveal differences which cannot be discerned on the ground or are judged inconsequential, such as differences in litter accumulation or some noncompositional effects of grazing. Even well-timed, high-resolution aerial photographs, whether panchromatic, color, or color infrared, are not a substitute for an on-the-ground examination.

It is often possible to combine information sources when producing the final vegetation map. Aerial photographs and plastic overlays portraying topographic features and ground truth information can be aligned on a high-intensity light table in a semi-dark room. Thus, a number of information sources are simultaneously visible to illuminate patterns for final mapping.

Site Maps

Some regulations require a range site map; a habitat type map would be similar in many respects, for both are site maps. Range site* mapping units are usually named for some soil and moisture characteristics, while habitat types are units of land named for the potential climax community.

These systems offer a major advantage for comparative purposes, such as extrapolating study findings to other areas, and are useful for reference area selection when used in conjunction with a detailed description of the existing vegetation. However, they cannot be considered a valid substitute for a description of the actual vegetation due to the range of plant communities possible for a single range site or habitat type.

Used above, both range site and habitat type maps present an oversimplified and theoretical view of the vegetation which is not sufficiently precise to compare reference area communities with communities in the affected area. The problem stems from the compositional variation which may be encountered on even highly similar sites. It is particularly inappropriate to use production ranges specified for this type of classification as the sole basis for revegetation comparisons, because production estimates both above and below the specified ranges may be encountered.

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*"A range site is a distinctive kind of rangeland that differs from other kinds of rangeland in its ability to produce a characteristic natural plant community. A range site is the product of all the environmental factors responsible for its development. It is capable of supporting a native plant community typified by an association of species that differs from that of other range sites in the kind or proportion of species or in total production." (National Range Handbook 1976). While it is difficult to argue with a classification which incorporates all environmental factors, there may be considerable room to question just what this means and how it has been accomplished.

The place of range condition classes, no matter how appropriate to range stocking, is questionable in premine inventories and revegetation assessment. Range condition classes are based on a climax view which is not always appropriate and must in any case be taken on faith, the climax for the study area often being extrapolated from a rather low number of sample communities which may differ in important respects. The effects of climate are often insufficiently incorporated into range condition determinations, as is shown in Part IV.

Above-Ground Net Primary Production

Herblands and Simple Shrub/Herblands

Most coal mines in this region are located in herblands (often grasslands) or shrub/herblands for which a harvest method of production estimation is appropriate. A good deal of information is available in the literature on harvest techniques, and an especially useful reference on both harvest and other production sampling procedure is by Milner and Hughes (1968). Root production is seldom sampled for premine vegetation inventories or revegetation comparisons, but techniques are available (Singh and Coleman 1973, Knievel 1973). Some general considerations will be discussed here.

Exclosure Technique. Production cannot be accurately estimated using harvest techniques when a significant but unknown amount of the current year's production has been removed by herbivores. The single aim of exclosures is to prevent the larger herbivores from eating plant biomass in the production sampling area prior to sampling. A maxim of ecology states that you can never do just one thing, and detailed consideration must be given to exclosure technique. Two major effects of exclosures must be considered: the effect of the exclosure structure itself, and community processes (e.g., plant succession) set in motion by the cessation of grazing when this has been a significant historical factor.

Effects of exclosure structures, which are usually a combination of woven and barbed wire fencing, include leachates (e.g., zinc from galvanized metal), bird droppings, shading, and effects of diminished wind velocity and moisture accumulation or interception. Of these, probably the greatest effect results from the accumulation of drifting snow along fence lines, and this is enhanced if blowing plant material had previously accumulated along fences. Exclosures may also become refuges for rodents, with destructive results.

In one exclosure approach, small temporary exclosures are set out prior to the start of annual grazing. These exclosures are moved every year. The advantages of this approach are cheapness and avoidance of rodent and snow accumulation problems. On the negative side, the effects of bird droppings may be noticeable, wind velocity is diminished, and the microclimatic regime is generally altered. Some shading and precipitation interception occurs. It is not uncommon for livestock to reach through, move, or overturn such exclosures.

The alternative is large exclosures, which are usually permanent because of the cost of construction. In this case, the effects of the exclosure structure can be largely avoided by designating a smaller sampling area within the exclosure. The perimeter of the sampling area should be approximately five times the fence height from the exclosure perimeter. If rodents become a problem, they must be trapped or poisoned. One advantage of permanent exclosures is that they may be useful sites for study of other vegetation parameters in addition to production.

A sample area of 2,500 square meters or more is desirable for long-term studies involving annual sampling, but homogeneity is more important than size if both cannot be obtained. In rare instances, it may be possible to contain several reference communities in a single exclosure. A sample grid layout simplifies sample plot location selection and identification as well as designation of areas reserved for nondestructive sampling. A rectangular exclosure shape greatly simplifies grid layout and precise location of sample plots.

The type of fencing material used depends upon the type of herbivores to be excluded. Four strands of barbed wire are sufficient for cattle and horses. Thirty inches of woven wire topped by two strands of barbed wire will further exclude lambs and lagomorphs. Common fencing materials do not restrict rodents or insects, and any fencing material which would restrict these herbivores would have very consequential effects on microclimate.

Literature on the effects of cessation of livestock grazing reveals highly varied results (Costello and Turner 1941, Gardner 1950, McLean and Tisdale 1972). Effects may result from a shift in the selective importance of grazing tolerance versus competition or from litter accumulation, which can tie up nutrients and lower soil temperatures.

Water intake of the soil may be affected (Rauzi and Kuhlman 1961, Hanson *et al.* 1970). Species composition may change, microclimate may be altered, the representativeness of the sample community may be lowered, vigor may increase resulting in higher stress tolerance, and so on. These considerations argue against total exclosure. Temporary exclosures avoid these problems.

In permanent exclosures, these exclosure effects can be reduced through controlled grazing following the last sampling for that year. Gates at each end of the exclosure may merely be left open in the hope that livestock will be enticed into the exclosure, or livestock may be penned in the exclosure until the desired results are obtained. In either case, close observation is necessary. Other possibilities with the potential for undesirable as well as desirable effects include mowing, raking, or even burning, none of which is equivalent to grazing.

Precision and Accuracy. Production data are used largely for comparative purposes--comparing the production of plant communities in the affected area with reference communities and the production of reference communities with revegetated communities. The two most important attributes of the production data for these purposes are precision and accuracy. *Precision* refers to the repeatability of measurements and the nature of their distribution, while accuracy concerns the nearness of production estimates to actual community production.

Precision is largely a function of the vegetational homogeneity of the sample area, the size and number of samples taken, and the level of stratification at which data are compared. Assuming that a single community is present in the sample area, homogeneity is a function of the type of population dispersion exhibited by the species present (random, clumped, regular, or a combination of these) and the scale at which they are examined. For example, a community dominated by a single, regularly dispersed herb species may appear relatively uniform at a scale of less than one-half square meter. In contrast, a community dominated by a large shrub and two herb species exhibiting random and clumped distribution may appear relatively uniform at a scale of several square meters.

Large samples and a large number of samples both contribute to precision, but efficiency must be considered. The size and number of samples should be chosen to optimize the balance between the increased uniformity attained through larger samples versus the statistical advantage of increased "degrees of freedom" obtained with a larger quantity of smaller samples which, taken individually, portray the vegetation as less homogeneous. Proper quadrat size and quantity will result in the minimum coefficient of variation for the data resulting from a given amount of time spent sampling. (See Wiegert 1962, VanDyne et al. 1963.)

In mixed communities, a sample number selected to obtain a specified degree of precision for total community production will result in a less precise production estimation when dominant species groups are considered, and even less precise estimation for single dominant species. For example, the minimal level of precision sometimes considered desirable for community production estimation is represented by a sample mean within 20 percent of the population mean at the 80 percent probability level. In a rather homogeneous community dominated by three grass species, this level of precision may be attained with five to ten samples. However, a similar level of precision for each dominant species may require many times that number of samples (Mueggler 1976). Because comparisons may eventually be desired at the species or species group level, it is advisable to err on the side of more precision than thought necessary since there is no way to go back in time to collect more data for earlier years. For premine reference area revegetation production comparisons, it is more desirable to obtain a community sample mean theoretically within 10 percent of the population mean at the 90 percent probability level.

Precision and accuracy are strongly related when sampling procedures provide data representative of community production. In some cases, this condition is not fulfilled. To obtain representative data for net above-ground primary production, careful species identification and harvesting procedures are necessary. Clipping to the ground results in the truest estimation. Even so, all species will not be sampled with equal accuracy due to plant morphology. For example, mats of *Bouteloua gracilis* are notoriously difficult to harvest properly in dry years, and a disproportionately high percentage of the short foliage is mixed with litter or remains unclipped.

A second source of error can arise from the seasonality of the plant species present in the vegetation. Production is usually estimated at a single sample date, the supposed time of "peak standing crop." This approach is accurate only when the phenologies of the dominant and subdominant species are sufficiently similar so that the peak standing crop is actually indicative of total community production. Often it is more accurate to take successive samples in order to estimate the peak standing crop for each major species individually or even to incrementally sum biomass increases.

The latter methods can result in higher production estimates--more so in communities with phenologically diverse dominant species. In four mountain grassland communities in Montana, Kelly et al. (1974) found that community peak standing crop estimates were only two-thirds of summation of species peak standing crop estimates, which in turn were half of estimates based upon incremental summation of biomass increases by species.

A third major source of inaccuracy can arise from the reference area approach, in which the reference area communities act as surrogates for communities in the affected (mined) area. Reference and affected communities are seldom compared using production data, and it is possible that the reference communities will not accurately represent production of the communities in the mined area. Even if production of the two communities is similar in one year, there is no assurance production would be similar in other years (see Part IV).

Accuracy is also diminished if part of the herbage is consumed. Grasshoppers, in particular, can raise havoc with production estimation. Pesticides may or may not be appropriate, but in any case the severity of the outbreak and extent of damage should be estimated (Anderson 1961, 1964; Putnam 1962; Mitchell and Pfadt 1974; Walcott 1944; Wiegert 1961).

Double Sampling. The production of a species can often be strongly correlated with some simpler or quicker estimation such as coverage, visual obstruction, basal cover, crown volume, etc. Some techniques are described by Evans and Jones 1958; Frischknecht and Plummer 1949; Payne 1974; and Robel et al. 1970.

A consistent approach showing a strong correlation or regression can offer considerable savings or the potential to obtain higher precision and accuracy for a given effort. However, this approach also introduces the potential for serious error, especially when continuity of investigators is not assured; thus, this approach should be evaluated with caution before adopting it.

Forest and Tall Shrub Communities

The understory of forests, woodlands, and tall shrub communities is usually estimated using the harvest methods previously discussed. Direct harvest measurements for the larger species are often impractical, and community production estimates based on gas exchange rates for photosynthesis require great effort and expense.

It is questionable whether productivity comparisons of mature and revegetated communities containing large and long-lived species are appropriate. Certainly it does not make sense to compare 75-year-old forest stands exhibiting 75 percent canopy closure with 10-year-old stands with 15 percent canopy closure. Stocking rates (density) and growth rates (site indices) are more appropriate for this purpose. (However, site indices may be poor indicators of herbaceous plant production; Basile 1971.) If production data are necessary for comparisons, an indirect, nondestructive* approach in which standing crop is mathematically related to rather simple measurements such as height, age, mean annual increment, or diameter may suffice. A limited amount of this type of information is available for selected shrubs (Ohmann _et al._ 1976; Brown 1976).

In some cases it may be possible to use regional volume tables prepared by the U.S. Forest Service for the major tree species of each region. These tables are derived from extensive sampling and result in good estimates of wood volume (cubic feet or Scribner board feet) when diameter at breast height and total height are known. However, diameters of at least 6 inches and heights of at least 40 feet are usually required. Moreover, these tables estimate wood only.

If production or aerial biomass comparisons for tree or tall shrub species are genuinely needed, a research effort of considerable magnitude may be required. Through destructive sampling, production or biomass data for all age or size classes must be obtained for production or biomass by category (trunk, stem, twig, foliage, etc.), along with measurements of potential predictor variables (crown area, height, age, diameter at various points, etc.). For each age or size class, the usefulness of the predictor variables will have to be assessed using several types of equations such as linear, exponential, allometric, and hyperbolic. The relative error of the various equations and predictor variables will have to be determined, and the best predictor variables and equations identified. To the author's knowledge, this has never been done as a part of premine vegetation inventory or mine revegetation analysis, and there seems to be little need to go into methodological details here.

Because height growth is less affected by stocking density than other size factors, height growth may be a better basis for comparing tree stands than production. The appropriate information can be obtained for the premine or reference stands by boring and aging selected trees at height intervals of several feet and graphing the results (height/age). All age classes should be sampled to reduce the effects of climatic variations. These data can provide a basis for evaluating revegetated stands.

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*Destructive sampling will be necessary to determine the relationship between standing crop and other parameters, but not for subsequent comparisons.

Crop Production

Cultivation is generally regarded as a higher land use than grazing, and reclamation to crop production might be considered more important than reclamation to rangeland. The reference area approach is very well suited to cropland reclamation evaluation because genetic variability can be limited and many of the factors governing production are controlled.

Some nonclimatic factors which should be considered in reference area selection or later comparisons include: time of planting, weed control and fallowing practices, pesticide application, seed application rates, fertilization, the number of years a field has been in use, and genetic variety, purity, and viability of seed. When possible, the same machinery and personnel should be used in both areas.

Cover

Cover may be defined in several ways, including leaf area index, which refers to leaf or blade surface area per unit land surface; foliar cover (sometimes called ground cover), which refers to the percentage of the sample area overlain by above-ground plant parts when viewed by looking directly up or down at them; and canopy-coverage, similar to foliar cover but in this case, the horizontal extremities of each plant are connected in the mind's eye to form a polygon, the entire area of which is used as a basis for determining the percentage of the sample area "covered" by the plant. "Basal cover" is not a cover measurement in the conventional sense in that foliage is not considered. Foliar cover and canopy-coverage data may be absolute (arrived at by mentally compressing the vegetation to determine the percentage of the sample area covered by each species) or relative (calculated by dividing absolute cover per species or group by total cover for all plants).

While very descriptive, the leaf area index is seldom used because of the great effort necessary to sample complex communities. Both canopy-coverage and foliar cover can be useful for premine vegetation inventories and revegetation analysis, although proponents of either approach are sometimes intolerant of the other. Canopy-coverage is easier to estimate in many cases and is useful for descriptive ecology and for collecting reconnaissance vegetation data. Comparisons based on canopy-coverage may be inappropriate when based on categories such as "perennial grasses," which fail to distinguish obvious differences between caespitose, rhizomatous, or mat-forming grasses. Foliar cover may be more appropriate for detailed comparisons of plant communities and is generally more useful in assessing the degree to which vegetation prevents erosion, although other factors must be considered. Basal cover (sometimes called basal area) is a special case which is useful in grazed rangeland, mainly for compositional comparisons, and in forestry as a measure of stocking.

Adequacy of cover sampling can be evaluated by plotting the number of species encountered versus number of samples, or the average cover of specified species or groups versus the number of samples, whichever is more appropriate to study objectives. The order in which data are entered can affect results in nonuniform vegetation, and it is possible to manipulate apparent results by selecting the sequences in which data are entered.

Before discussing methods, it is worthwhile to consider that both canopy-coverage and foliar cover are frequently affected by adverse sampling conditions to a significant extent, and even the attempts of expert investigators capable of estimating cover with high resolution may be confounded. Winds may result in the foliage and some sampling apparatus being in a constant state of agitation or distortion much of the time, and the investigator may have to choose between sampling under this common condition--or not sampling. Heavy rain, hail, the trampling or bedding of animals--all can have a significant effect on cover estimation, yet none of these factors is reflected in statistics related to cover estimates, and some claims for high precision and accuracy in cover estimation fail to describe the conditions under which sampling was performed.

The following three major methods of estimating cover (ocular, line intercept, and point intercept) vary in their suitability depending upon sampling conditions, plant morphology, and community structure. It is best to test one or more methods on the communities under consideration before selecting a method(s).

Ocular Estimations

Ocular estimates of canopy-coverage or foliar cover are very popular for premine inventories and revegetation analysis. Quadrats are often 1 square meter or less, although larger quadrats are sometimes used for reconnaissance. Estimates are most commonly made for nested quadrats. The quadrat frame may be calibrated or provided with crosswires or an acetate overlay to provide references of known area. Cover of the upper strata of forest or tall shrub communities may be estimated using a periscope-like device which incorporates a grid.

Estimates are sometimes made in increments of one to several percent, or cover classes representing a specified range of values may be used. Some common cover scales are the Domin (ten classes), Braun-Blanquet (seven classes), and Daubenmire (six classes). The chief advantage of using broadly defined cover classes is the low likelihood that errors will be made, even in large quadrats or with insufficiently trained or undiscriminating investigators. Results averaged from a large number of samples tend to provide good accuracy, but biased results may occur. For detailed comparative purposes, a higher level of resolution is both desirable and possible when experienced observers have calibrated their estimates using another cover estimation technique, such as the point intercept method. Pantographs, though time consuming, are also good for comparative analysis. A color slide of each quadrat taken from the perspective of the investigator can be quite valuable should questions arise later.

Ocular estimates can be suitable for premine inventories and revegetation assessment, but this technique is not without problems. First, ocular estimates require that the coverage of individuals be mentally "compressed" to arrive at cover values for the species, and such mental gymnastics and the degree of compression can result in differences in estimates among observers. Second, once the saturation point of 100 percent cover is reached--even for a portion of the quadrat area--or when overlay occurs, differences in abundance are not reflected in cover data as they would be from production or leaf area data. Third, some plants or plant parts may be obscured from sight. This problem becomes more serious in overhead strata or in large quadrats. Fourth, it can be physically impossible to place solid-frame quadrats where desired in some tree or shrub communities. Fifth, lighting conditions can affect ocular estimates.

The above caveats are meant to point out some limitations of ocular cover estimates, which can nevertheless be useful and reliable. This may make it sound as if the ocular estimation of cover provides questionable data. Other cover estimation techniques also have attendant problems, some of them more serious.

Line Intercept

In this approach, a line--theoretically one-dimensional, but actually a measuring tape in many cases--is strung between two points and the length of the line segment crossing plant parts is measured and recorded. Care must be taken to assure that the line is contained by the community being sampled. A plumb or small-diameter rod with leveling apparatus, such as a target level is used to evaluate vegetation above or below the line. The vegetation may be sampled by vertical strata. Length segments are summed and converted to a percentage of total line length to calculate cover. The line intercept method can be used for foliar cover, canopy-coverage, or basal cover. Of these, foliar cover is most difficult to measure accurately.

This method seems to afford better quantified cover estimates than the ocular approach, but practical problems often limit accuracy. Measurements are slow and require painstaking care, particularly in complex communities or when measuring foliar cover, and it is easy to lose track of what has or has not been measured. It may not be possible to locate a straight line randomly in shrub or tree communities, and use of a vertical rod in these communities may not be feasible. Winds may make it difficult to determine the points of interception and, if a measurement tape is used as the "line," enormous force may be required to hold the tape straight against the wind. Tall foliage and single-stem grasses pose special measurement problems. In general, this method is most appropriate for low or mid-height vegetation and species with high crown density.

Point Intercept

In this method, a pin (e.g., a sharpened bicycle spoke) or a set of pins in a frame are lowered--usually vertically--through the vegetation, and contacts of the tip or point are recorded until the tip reaches ground level. Hits may be defined on the bvasis of canopy-coverage or basal cover, and this method is particularly good for estimating foliar cover.

The point intercept method is really a frequency measurement from which presence or absence data are obtained. However, when the area of the "point" is so small (e.g., a millimeter or less) that two individuals of the same species are seldom hit by a single pin drop, this technique can estimate cover if cover is the basis for the inclusion. Vertical strata may be evaluated separately.

As with other methods of cover estimation, winds can affect results and the number of hits resulting from lowering the pin into a bunch of caespitose grasses can be impossible to count. Sometimes plants "hit" must be moved to allow further pin lowering, resulting in an effect on subsequent hits. Overhead hits, determined by using a vertically oriented telescopic rifle sight, record only the first plant parts visible, others being obscured by the lower ones. Several hundred samples must be taken to collect species composition data that include the rarer and smaller species.

Diversity

Species Diversity

Thinking about species diversity has proceeded in two opposing directions: (1) increasingly sophisticated mathematical approaches to evaluating species abundance relationships, and (2) increasing skepticism concerning the role of these calculations. Neither viewpoint has had any noticeable effect on reclamation guidelines that specify species diversity evaluations.

A review of diversity indices and concepts is beyond the scope of this paper, but the subject is covered in numerous texts and a short review is provided by Peet (1974). More important than a technical review of various formulae and indices is a reconsideration of the role of species diversity calculations in revegetation assessment.

Species diversity was included in reclamation requirements primarily because of a supposed relationship between species diversity and community permanence, whether through inertia, resilience, or some other type of adaptiveness. It is questionable that such a relationship exists. Goodman (1975) concludes his treatise on the diversity-stability hypothesis by stating:

> We see, therefore, at several levels of analysis, that relative population stability can be understood as an evolved trait which is, in large part, an intrinsic characteristic of the population rather than a passive reflection of simple food-web phenomena. This conclusion, however, unstartling it may be, contravenes one of the basic assumptions which led ecologists to anticipate that community stability is determined to a significant extent by community trophic structure.

Goodman's main points are worth considering here, although they are by no means universally shared.

Summary and Conclusions

We may recapitulate the major points of this review of the diversity-stability hypothesis as follows:

a) The original lines of evidence cited in favor of the hypothesis are so peculiarly fragmentary that, from them alone, no sensible conclusion may be drawn.

b) Shannon-Weaver diversity is a dubious index. The biological meaning of what it represents is unclear; these are not available criteria for precisely measuring community diversity under natural conditions.

c) The transfer of the vocabulary of thermodynamics and information theory to the ecological hypothesis is not justified by physical theory but is merely a superficially attractive analogy that might have proved to be "heuristic" had the predictions of the hypothesis concurred with the fact.

d) The two major types of modern empirical approach to the subject are systematically ambiguous for reasons that are inherent in their respective methodologies, and they cannot serve to discriminate critically between the diversity-stability formula and some alternative hypotheses.

e) The available empirical studies which are more accessible to interpretation, with one exception, contradict the expectations of the diversity-stability hypothesis.

f) The available nontrivial computer models of food webs generate results that contradict the expectations of the diversity-stability hypothesis.

g) The well-developed mathematical literature supporting the diversity-stability hypothesis is based on analysis of infinitely unlikely equilibrium conditions and inadmissible techniques of mathematical approximation. Other kinds of analytical treatment of mathematical representation of food webs variously imply that there is no relationship between diversity-stability or that stability decreases with diversity. This entire literature is so permeated with assumptions, crucial to the derivation of the particular mathematical results but violated by any conceivable ecological system, that the extrapolation of these results to ecology is defensible only as speculative analogy.

h) The original formulation of the hypothesis presupposed that the intrinsic stabilizing or destabilizing mechanisms accessible to individuals or populations are unimportant. Abstract evolutionay reasoning, theoretical life-table analysis, and some models and experimental studies of life histories or population growth rates indicate to the contrary that stability or instability should be considered adaptive responses of the population. Examples of strong selection for stability suggest that selection may obscure whatever mathematical consequences accrue from food-web complexity.

The function implications of species diversity calculations are largely unclear and unproven. This does not mean that formulae used to evaluate species abundance relations cannot be useful for comparing communities, whether or not these formulae measure something called "diversity" and whether or not what they measure is related to community permanence or some other attribute. This includes the Shannon formula, which is most sensitive to changes in abundance of rare species, as well as other indices. However, their role in revegetation assessment is not clear, and regulatory agencies requiring the uses of such formulae should perhaps explain what they hope to accomplish through calculating diversity indices.

Other Diversity Concepts

The leap from legal requirements for a "diverse permanent cover" to guidelines specifying the use of species diversity indices was probably unfortunate. The species may not be a particularly appropriate unit for evaluating diversity. It is obvious that species are not equally different, and requirements for a diverse cover should take this into account. A distinction should also be made between the internal diversity of a community and a diversity of communities. See Part III.

Reference Areas

Reference area communities serve as paradigms for communities or community types in the affected area. The ultimate determination of whether the postmining vegetation is comparable or superior to premining vegetation depends in part on the representativeness of the reference area communities and the quality of the classification used to describe the original vegetation. Finding good reference areas can be very difficult as communities which are similar in some respects in some years may not appear to be very similar in other years (see Part IV).

For descriptive plant ecology, a combination of methods for estimating abundance is superior to reliance on a single method, each of which is better suited to some growth forms and sampling conditions than others. This fact is often overlooked while attention shifts to comparative technique.

The best approach is to list the growth forms and sampling conditions which will be encountered and pick the most appropriate methods. For example, ocular estimation of cover has wide application, but density estimates for shrubs or single-stem rhizomatous grasses may provide a useful supplement. Basal cover may be useful in comparing grazed vegetation. However, density data are meaningless for mat-forming species, and basal cover estimation for large caespitose grasses may be far from precise. Production comparisons between premine and reference communities are highly desirable if production will later be used to evaluate postmining vegetation. The point is that a variety of methods, each well-suited to some species groups and not necessarily applicable to other groups, is better than reliance on a single method. Table 2 provides an example of matching methods to growth forms.

TABLE 2. MEASUREMENT METHODS MATCHED TO GROWTH FORMS (EXAMPLES).*

	Growth Form				
Measurement	Single or few stemmed herbs, shrubs	Mat-forming herbs	Caespitose grasses	Multiple stem or rhizomatous herbs, shrubs	Arborescent
Production	Good	Fair; variable	Good	Good	Poor
Ocular cover	Density-dependent	Good	Good	Density-dependent	Fair; variable
Point intercept	Usually good	Variable	Poor	Usually good	Poor
Line intercept**	Fair	Good	Fair	Fair	Poor-good
Density	Good	Poor	Good	Fair; variable	Good
Basal area	Fair	Good	Fair	Fair	Good
Variable plot	Poor to fair	Poor	Poor	Poor	Good

*Average suitabilities are indicated, but particular sampling conditions may affect choice.

**Suitability depends on line height.

The reference area approach requires two levels of comparison: (1) comparisons of communities in the affected area with selected reference communities, and (2) comparisons of reference communities with revegetated communities. The effects of estimation techniques and sampling conditions, discussed earlier in this section, can strongly influence data and hence comparisons. In the experience of the author, sampling errors resulting from inadequately trained investigators or perhaps from lack of meticulous sampling under trying circumstances can be even more serious (see Smith 1944 and Pechanic 1941). For example, data comparisons specifying means within ten percent of each other presume a level of accuracy may not exist.

The species is the most appropriate unit for comparing premine and reference vegetation. For comparing reference communities with postmining communities, species groups such as annual or perennial grasses or forbs are often used. Depending upon how abundance is defined, more discriminating species groups may be desirable.

Several comparison techniques are possible. A similarity index may be used with floristic abundance data only or with floristic data and quantitative nonfloristic data. A T test may be similarly employed, or indices of species abundance relations may be used for comparative purposes. When quantitative phytocenological work has been performed (e.g., cluster analysis, synthesis tables, ordination) for the premine vegetation, the procedure may be repeated for an appropriate subset of the data (e.g., data from those stands comprising one community type), including data from the candidate reference community. The results are indicative of the relation of the reference community to communities in the affected area.

Stand homogeneity is another important consideration for reference area selection, as well as the usual consideration of sample size, number, shape, precision, accuracy, etc. Comparisons using data collected in different years, hence under different climatic regimes, are not valid. In particular, it is inappropriate to compare reference data collected in one year with pre- or postmining data collected in another year unless it can be shown that significant changes in species abundance have not taken place.

PART III. RECOMMENDATIONS

This section recommends some possible improvements in premine vegetation inventories. Technical considerations covered in Part II, and which are thoroughly discussed in the literature and various texts, are not considered here.

If a primarily descriptive approach is used, premine vegetation inventory requirements rightly specify cover and production estimations, and woody plant densities are appropriate when it is desirable that such growth forms become part of revegetated communities. However, some inadequacies are evident in inventory requirements. The classification of vegetation is critical to all subsequent areas of study, for the identified community types (or vegetation types) provide the basis for vegetation mapping and reference area selection, and all subsequent measurements are tied to the classificatory units. In short, the classification defines the vegetation for purposes of inventory and later comparisons. It is, therefore, something of an enigma that such an important topic is not addressed by the guidelines. As a result, some classification are subjectively determined from rather casual observation or sampling of the vegetation, and vegetation mapping and reference area selection suffer.

Diversity is too narrowly defined in term of species abundance relations. A functional approach to revegetation evaluation is offered as an alternative to a primarily descriptive approach. Finally, and perhaps unavoidably, procedural compliance with the guidelines does not assure that the data collection will result in contributing to an understanding of the communities involved which may be possible through close scrutiny of the data and exploratory analysis.

Phytocenology* and Classification

Some of the keenest minds in phytocenology have directed their attention to ways of calculating and portraying affinities and dissimilarities among plant communities. The resulting formidable body of literature presents a variety of compelling but often controversial viewpoints which are at best not easily synthesized, and at worst contradictory. Perhaps this is why premine vegetation inventory requirements ignore this topic. Furthermore, even when relatively objective procedures are used to evaluate and portray community relations, classification inevitably requires judgments which cannot be strictly prescribed. However, it would be better if regulations prescribed general classificatory requirements which allowed considerable latitude than to ignore the issue, as is presently the case.

The human mind is very adept at classifying things. Gilmour (1951) maintains that classification is the prerequisite for all thought, while Kucera (1973) states that without classification data become meaningless. Webb (1954) asserts that some system of typification and recognition of plant communities is necessary to a properly based science of vegetation. Classification of plant communities seems to be necessary for premine inventory and comparative purposes. However, while the utility of classification is generally agreed upon, the appropriateness of classification is not.

Early in the development of phytocenology in the United States, Clements' (1916, 1936) organismic views were influential. Clements thought that species were organized in communities and communities into broader groupings in a manner analogous to the organization of cells into tissues, organs, organisms, and so on. Less influential were Ramensky (1924) and Gleason (1926), who pointed out that species are individualistic in their requirements and tolerances, that their distributions are therefore not shared, and that chance events played a role in the composition of communities. These views resurfaced in the 1950s and 1960s. McIntosh (1967) identifies a fundamental question of classification when he asks, "How many intermediaries must be interspersed between 'types' before they are lost as types and become continuous with one another?"

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*The term "phytocenology" refers to the study of vegetation or vegetation science and is used here in preference to "phytosociology."

Each plant community is unique at some level of measurement, and compositional gradation within and between communities (a continuum) is undeniable, though not universal. However, the existence of compositional gradation does not imply a monotonous or constant degree of gradation. Daubenmire (1966) does not deny the existence of continua but notes that some continua can form the basis for classification. He argues the existence of "plateau-like areas exhibiting minor gradients separated by areas of steeper gradients, with the plateau-like areas being of sufficient similarity to warrant being designated as a type." Poore (1962) also recognizes that vegetational variation is continuous, but, nevertheless, well-marked communities are sufficiently alike to be conveniently considered as members of a class.

In this paper, the advice of Goodall (1963) is taken: Because subdivisions of a continuous variable into classes involve a loss of information, ordination or some other analytical procedure which reveals community relations should be applied first, with classification following and incorporating the results. This approach can help answer questions such as: Are there plateau-like areas along the continuum? Are some communities sufficiently similar to warrant recognition of them as members of a class of communities called a community type? How is similarity determined, and how much similarity and how many communities are necessary for designation of a class to be appropriate? How can communities belonging to these groupings be recognized?

Of the broad array of classificatory procedures available, rather few are appropriate for premine vegetation inventories which will serve as the basis for the types of comparisons required by law. It is clear that the vegetation should be of the existing vegetation and that a floristic level of detail is necessary. Species composition, using some abundance measure, seems to be the most appropriate basis for comparing communities.

Procedures are available that can greatly assist development of a classification by portraying communities in a way indicative of similarities in community species composition. Three such methods are briefly discussed here: ordination, cluster analysis, and synthesis tables. Ordination and cluster analysis are analytical procedures made practical by the advent of the computer, while synthesis tables are a technique for making orderly comparisons and rearranging data to make community grouping and species distributions among communities more evident. All methods require reconnaissance sampling of plant communities in the geographic area under consideration.

Vegetation Reconnaissance

Since the classification of vegetation is so important to subsequent study, an effort should be made to develop an unbiased classification which avoids a preconceived concept of how communities are (or should be) organized. The goal is to classify the vegetation based upon natural affinities or differences among communities. It is not appropriate to identify types on the most obvious or subjective grounds and then set out to prove their existence by sampling, as some guidelines allow, for the result can portray the vegetation incorrectly.

The communities must be sampled in a manner which reveals community species composition based on some abundance estimation technique. Ocular estimation of canopy-coverage is often chosen because meaningful compositional data can be gathered quickly relative to other techniques. Other methods may be more appropriate under some circumstances, such as basal cover in grazed communities. Site information may be recorded at the time of sampling if an evaluation of site factors and vegetation types will be desired.

A goal of reconnaissance is to sample as many communities as possible--for sample areas (up to a few sections) it may be possible to sample all communities. In the interest of efficiency, a single large plot per community may be sampled. The plot should be large enough to contain at least several individuals of all dominant and subdominant species. Of course, if time and money allow, a large number of small plots may be sampled. In either case, cover classes, such as those popular among European phytocenologists, are appropriate.

Plot location should not reflect preconceived bias, but plots should not be located across recognizable community boundaries. Any communities identifiable from aerial photographs should be sampled.

Examining the resultant data will probably reveal that, with the possible exception of very simple communities, no two communities sampled will appear to be identical, just as it is unlikely that two samples from the same community would appear identical. However, some communities may appear to be quite similar, others very different. The data may be aligned or portrayed in various ways to make these similarities and differences more evident.

Analytical Procedures

Two analytical and one organizational method for evaluating and portraying community relations will be briefly described here: synthesis or association tables, polar ordination, and cluster analysis. Other methods such as factor analysis, principal component analysis, or discriminant analysis may be similarly employed with varying degrees of success. All methods are best understood by reviewing detailed accounts of their application, followed by applying the procedures to data with which the investigator is familiar. This sort of detail is not possible here, and the reader is referred to Bray and Curtis (1957), Gauch and Whittaker (1972), Swan *et al.* (1969), and Junk (1973) for ordination and Sokal and Sneath (1963) and Everitt (1974) for cluster analysis. The tabular approach is hardly explained by its originator (Braun-Blanquet 1932) and is somewhat mystifyingly reviewed by Poore (1956), but better explanations are provided by Mueller-Dombois and Ellenberg (1974) and Kuchler (1967). Mueller-Dombois and Ellenberg (1974) is also recommended for a discussion of all three methods.

The methods discussed here involve considerable computation, and in some cases the amount of computation varies as the square of the number of samples. This can be a significant consideration for large data sets, even when a computer is used, for data storage space may be insufficient. Therefore, any preliminary subdivisions of the data which are highly desirable and defendable should be made initially and the methods applied to the data subsets. For example, if communities containing a specified abundance of trees, shrubs, or some other structurally defined species group are deemed necessary for wildlife habitat purposes or other reasons, these communities should be evaluated separately. In addition to reducing computations, results may be enhanced, as in ordination when lower total dissimilarity of communities may necessitate construction of fewer axes and result in easier interpretation. In the following discussion, data from the reconnaissance samples will be taken to be indicative of actual community composition.

Synthesis Tables

Synthesis tables are a method of orderly tabular comparisons which primarily uses constancy* data. They are best suited to rather small sets of data. All plant species encountered in reconnaissance samples are listed on one axis of an initial table, while samples, usually identified by numbers which are nominal, form the other axis. For example, the abundance of each species in each sample plot is indicated by cover class midpoint values or perhaps by cover class numbers themselves.

Consideration is then shifted to species of intermediate constancy. The range of constancy values selected is arbitrarily arrived at, and the judgment and experience of the investigator are useful in determining what levels of constancy are appropriate. The idea is that species of high constancy have broad ecological amplitudes and are characteristic of most of the stands sampled, while species of low constancy are indicative of accidental occurrence. Obviously, the diversity of communities (Whittaker's [1972, 1975] Beta diversity) affects the evaluation of constancy values. For large data sets which include data from diverse communities, species of low constancy may be indicative of distinct communities of small areal extent, and so the lower range of constancy values excluded from consideration is usually much smaller than the upper range.

A new table is constructed with only these species of intermediate constancy listed in order of decreasing constancy. This table is scrutinized in detail to distinguish species groups which are characteristically found together in samples and are mutually exclusive of other species groups associated with other communities sampled--these are called differential species.

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* Constancy refers to the percentage of sampled communities in which a species was present. Thus, constancy is similar to frequency, but calculations are based on species occurrence in samples representing different communities rather than samples from a single community.

New tables are constructed with differential species (other species are not considered) organized into species groups. Samples are reordered according to the distribution of differential species in species groups. This is rather difficult to picture without an example but results in a table in which similar samples (defined using differential species) are grouped and trends in species distribution are evident. Further refinements are possible from visual inspection and by ordering species according to constancy and apparent ecological amplitude.

A final table is constructed in which samples are grouped on the basis of mutually associated species (previously described). Differentiating species are listed first, followed by other species in order of descending constancy. The data have been reordered to make similarities and differences between communities apparent.

Ordination

Ordination is an analytical procedure for aligning stands (actually, samples) in series along axes to express relationships among the stands. Ordination was developed as an alternative to classification. The idea is that since species distribution forms continue, classification of communities is inappropriate and stands should be represented in an unbroken manner which portrays community similarities and differences. However, ordination can provide useful information for developing a classification, for the results of ordination (which look like a scatter diagram) are often indicative of groups of similar stands as well as areas of compositional gradation.

There are many ordination techniques, but a general approach can perhaps be described. Communities are compared using some coefficient, index, or formula which measures "similarity." In choosing among these, the investigator does well to select one which yields easily interpretable results. A similarity matrix is constructed which indicates the similarity of each sample relative to every other sample. The sum of similarity (or dissimilarity) values for each sample is computed.

Attention is shifted to species with high dissimilarity value sums. Two of these samples which are themselves dissimilar are chosen as endpoints for contruction of an (x) axis. Sometimes the most dissimilar stands are taken to be "oddballs" and are not considered for endpoint selection. The entire set of samples is aligned along this axis using an index or distance formula. Some highly dissimilar stands may be clumped along this axis and to further differentiate among these a second pair of dissimilar samples from a cluster is chosen as endpoints of a new (y) axis. Calculations are made to align all samples along this axis, but as each sample now has x and y coordinates, the results portray a two-dimensional ordination.

If dissimilar stands are still clumped together, a third (z) axis may be constructed as previously described using dissimilar stands from some sample cluster. It is obvious that the selection of endpoints directly influences ordination results, and these endpoints may be selected to test various hypotheses. In some cases, axes may be indicative of environmental gradients, such as from hot to cold, dry to wet, or heavily grazed to ungrazed.

The ordination may proceed if necessary beyond a three-dimensional ordination. In some cases this may be useful, just as considering a niche as an N-dimensional hypervolume may be useful, but the practical interpretation of ordinations using more than three axes is problematic. The problems may be solved by dividing the data into subsets and ordinating the subsets, though of course bias may be introduced and results are more limited.

Cluster Analysis

Cluster analysis is an agglomerative procedure which was derived to answer questions of speciation (numerical taxonomy). For phytocenological purposes, it is well suited to large and/or diverse data sets. As with ordination, many techniques are available. A general description will be attempted, but numerous variations are possible.

A similarity or distance formula is used to compare each sample with all other samples and a matrix is compiled. The two most similar samples are identified and grouped ("linked") and their level of similarity recorded. These samples are removed from the matrix and in their place is entered a single "synthetic" set of data, computed in one approach by averaging the species composition of the component stands. Thus, each iteration reduces the matrix by one row and column. Similarities (or distances) are computed for the synthetic data and inserted into the matrix. The most similar samples are identified, and the procedure repeated until all samples or synthetic data are joined.

The investigator must decide such matters as whether synthetic data should be computed by averaging the latest entry and the previous synthetic data or by computing synthetic data as means for all component samples. Similarly, linkage can be accomplished using the average data for synthetic samples or by using the original similarities of component samples.

Results are usually portrayed in a "dendrogram." Samples are indicated in appropriate order on one axis while the other axis lists similarities from high to low, starting at the origin. In practice, the dendrogram must be constructed by working backward from the last grouping to the first, and samples cannot be properly ordered unless this is done. Linkage is portrayed by means of bars at the appropriate similarity levels joining stems from the samples or sample groups.

Limitations

These data analysis procedures are useful as they can reveal affinities and differences among communities and indicate the nature of community gradation. The results can be a great aid to classification, and bias is certainly reduced in comparison to nonanalytical classificatory procedures.

However, it is erroneous to think of these procedures as objective, for judgments and choices which affect results must be made at nearly every turn. These decisions, if intelligent and informed, are made to achieve desired results. Some examples of choices which affect results include the following:

Synthesis Tables

Synthesis tables are highly dependent on the capacity of the investigator to perceive ambiguous patterns in data and perhaps to solve puzzles. Specific choices include the selection of plot size, differential species, and an appropriate range of constancy values. A judgment must be made concerning when tabulation is complete.

Ordination

The biggest variable is often the selection of endpoints for axes construction. Other choices concern: what is measured; how accurate measurements are; selecting a community coefficient, similarity index, or distance formula; and deciding when ordination is complete.

Cluster Analysis

Once the cluster analysis procedure is set in motion, it proceeds to its inevitable conclusion. In some respects this is desirable, but the investigator never knows what almost was, for linkage is decided only on the basis of highest smiliarity (or shortest distance). Other choices which affect results are: what is measured, how accurate measurements are (remember, the computer may calculate similarities to ten decimals while cover classes of 20 percent may have been used), how samples are compared, type of linkage, and means of computing synthetic data.

These are not pro forma warnings, for these limitations can strongly affect results.* Before investing considerable time and money in any of these procedures, a thorough understanding of the effects of each choice is necessary.

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*The author once developed a cluster analysis computer program (at considerable expense) with gratifying results. Later he used a "canned" cluster analysis program developed for the social sciences on roughly similar data. This was a cost-saving measure. The results were difficult to interpret and did not appear to be indicative of community relations.

Classification

Classifications may be categorized in several ways: natural or artificial agglomerative or divisive, based on features of the vegetation or features outside the vegetation, hierarchical or typifying, large scale or small scale, and so on. Classifications based on features of the vegetation may use floristic or physiognomic classificatory criteria.

For purposes of premine vegetation inventories and reference area selection, rather few options are open for classificatory criteria. The classificatory units must be similar with respect to production, cover, species abundance relationships, and (in some states) seasonality. Similarity in these combines respects cannot be directly evaluated due to practical considerations--i.e., vegetation reconnaissance can hardly be expected to incorporate production sampling or perhaps even to evaluate species abundance relations, though this is more easily done.

A detailed classification based on floristics may provide sufficiently well-defined community types. It seems safe to assume that the full species composition of communities should more completely express the relationships among communities (and between communities and the environment) than would consideration of only one or a few taxa. Consideration of full species composition also incorporates diversity and seasonality factors and may be roughly indicative of production when community comparisons are made at a species-by-species level.

Montana guidelines specify classification on the basis of dominants, but this approach may be too restricted if the classificatory units are later used to evaluate diversity and seasonality. The synthesis table approach is also insufficient in this respect, for classification is based on constancy and differential species rather than on full species composition.

It seems that broad-scale floristic classification can best be made after comparing samples using some community coefficient, similarity index, or distance formula which is applied to the full floristic data. The author (and also others, see Gauch and Whittaker 1972) has found that Sorenson's (1948) coefficient of community gives good results that can be more or less intuitively interpreted, which is not the case for many other formulae sometimes used for comparing samples.

Some analytical procedure for evaluating and portraying community relations is highly desirable. Ordination and cluster analysis have been briefly described, but other techniques such as factor analysis or principal component analysis may be useful.

The problem is to identify clusters from the portrayed results. Some clusters may be rather unambiguously indicated. Areas of gradation as well as small clusters may also be evident, the significance of which is questionable.

When analytical procedures are used, it is sometimes possible to define some arbitrary criteria for identifying clusters, such as a specified level of similarity at which each stem of a dendrogram is taken to be indicative of a cluster if at least a specified number of samples are joined below that stem. Such an approach is objective but would not necessarily result in the most meaningful classification.

Another approach is to identify each sample portrayed in the ordination, cluster analysis, etc. in a way that allows recognition of the communities represented. For example, all species present at some specified level of abundance may be listed. In this way, clusters have some phytocenological meaning to the investigator. The identification of clusters can thus be based not only on the portrayed results of some analytical procedure, but also on the investigator's knowledge of the vegetation, both first hand and gained through literature review. It is appropriate to consider the ecological significance of the abundant or constant species in identifying clusters and also the possible misleading effects of only considering data from a small area. For example, some small tentative clusters may be indicative of transitional areas between rather unambiguously identified clusters representing community types. Other small tentative clusters may be indicative of distinct community types of small areal extent, which accounts for the small number of samples forming the cluster.

Classification is thus subjective but guided by analytical results portraying community relations. In this process, there is a potential to incorporate much useful information about abundant species and environmental factors and also a potential to introduce bias. Tentative community types (which are abstract classes of communities derived from sample data and which are theoretically descriptive of other communities not sampled) can be further evaluated and refined.

An average abundance and constancy table can be constructed with species on one axis and tentative community types on the other axis. The species which resulted in clustering are evident by their high abundance and constancy values. These diagnostic species, whether one or several, should have constancy values of 100 percent and should be abundant within ± 1 cover classes of mean abundance for the type under consideration. Samples not meeting this criterion are probably insufficiently similar to justify their inclusion in that community type for premine inventory purposes. Other anomalous samples in a tentative type may be identified if rather high abundance values for some species are accompanied by low constancy values, indicating either that a new type or phase should be identified or that the anomalous sample(s) is insufficiently similar to warrant inclusion in that community type.

The resulting classification should identify community types comprised of communities which can be considered essentially equivalent for purposes of premine vegetation inventory. This condition is necessary, even if it turns out that an undesirably small percentage of the samples is incorporated into the identified types. In such a case, classification may not be appropriate for a considerable portion of the affected area, or it may simply be that insufficient samples were taken.* If the latter is suspected, more samples may be collected and the procedure repeated. Of course, it is not valid to purposely sample certain communities to justify recognition of new community types. If a significant portion of the vegetation appears to form a continuum for which classification is inappropriate, these communities can be evaluated for reference area selection on a one-to-one basis.

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*The smaller the area from which samples were collected and the fewer the samples, the greater the likelihood that communities which may rightly comprise community types in a larger universe will appear to be outliers.

Community types should be described floristically in an unambiguous manner. A dichotomous key may be appropriate if the need arises for personnel not familiar with the classification to use it. Environmental factors can be associated with each community type after classification rather than used as classificatory variables.

The topics of phytocenology and classification are further discussed by the following authors: Anderson 1965, Bannister 1966, Beals 1960, Coupland 1961, Daubenmire 1960, 1968, Fosberg 1961, Franklin *et al.* 1971, Hughes 1949, Hutchinson 1955, Lambert and Dale 1964, Layser 1974, Looman 1963, Looman and Campbell 1960, Loucks 1962, McMillan 1959, Muller 1958, Orloci 1967, Pielou 1977, Poore 1955, 1956, 1962, Tansley 1920, Turner 1974, Whittaker 1967, Williams and Dale 1965, and Wilson 1981.

Diversity

In Part II, it was suggested that the place of diversity measurements, especially species diversity measurements, in premine vegetation inventories is not justified on the basis of the once popular diversity-stability hypothesis. Estimates of species-abundance relations may be used for community comparisons even though it is not always clear whether any fundamental community attribute is being evaluated or implied. Since numerous laws require a "diverse" cover of vegetation in reclaimed areas, and because the premine vegetation usually provides the standard for evaluating revegetation success, it may be appropriate to define diversity based on growth forms rather than species.

One problem with species diversity formulations is that species are treated as essentially equivalent units, but this runs counter to both fact and to other interpretations of diversity. For example, the rhizomatous species *Agropyron smithii* and *A. dasystachyum* are distinguished on the basis of some rather minute characters, most notably hairiness of the lemmas. For purposes of species diversity calculations, these species are considered as two distinct species--equally distinct as an annual forb and a tree species. For many purposes, including aesthetic and habitat diversity, it may be more appropriate to recognize classes of similar plant species which are used to evaluate diversity rather than to use species themselves.

Most diversity indices (except richness) require abundance data, which in practice are usually cover data, and comparisons based on cover are mandated by laws. It is possible to make comparisons based on cover data that are not only more indicative of similarity than total cover comparisons, but that also incorporate a concept of diversity which may be more meaningful for evaluating habitat and aesthetic diversity than commonly used species diversity indices.

In this approach, cover is estimated for similar species groups and the data from communities compared using Sorensen's (1948) coefficient of community. The usefulness of this approach hinges on how well species groups are defined. A comparison of cover of "perennial grasses" is only minimally reflective of diversity, but if "perennial grasses" is replaced by a number of more exactingly defined growth forms, an understandable diversity evaluation is made and cover comparisons become much more revealing.

A nonhierarchical set of species groups can be devised based on the flora involved and the diversity concept that seems most appropriate. For example, "perennial grasses" may be further divided on the basis of height, habit, and seasonality into species groups such as: bunchgrass--tall cool-season, tall warm-season, mid cool-season, mid warm-season, short cool-season, and short warm-season; single or few-stemmed rhizomatous--tall cool-season, mid cool-season, short cool-season, tall warm-season, mid warm-season, short warm-season, and mat-forming warm-season and mat-forming cool-season grasses. Such a system may be preferable to one based on floristics.

Other criteria would be appropriate for other species groups, and a hierarchical system based on major differences in growth forms could be used. The idea is to explicitly define group characteristics according to the concept of diversity employed. The current practice of allowing "weighted" diversity comparisons, which is questionable in any case, should not be followed.

Using the approach just described, comparisons of revegetated communities and the appropriate reference communities would be indicative of community similarity, diversity, and cover without specifying a similar species composition. Comparisons between revegetated communities would be indicative of whether a diversity of communities had been established and could be compared with similar computations for premine communities or community types.

Statistical Summarization vs. Data Analysis

The considerable expenditures entailed by premine vegetation inventories might be expected to have contributed significantly to such topics as the functional implications of species diversity indices, the relationship of climatic and other environmental factors on production and species composition, and other descriptive-functional relationships. This has not been the case. Furthermore, extrapolating findings to other geographic areas has been limited by lack of phytocenological study and haphazard classification which provides the framework for subsequent community investigations.

Collecting questionable or patently ridiculous data* is another stumbling block. Insufficient concern for careful sampling is evident at several levels. It is manifested by the "dumping" of data prior to submittal and the reluctance to draw conclusions from data comparisons. Companies offering premine vegetation inventory services stress their computerized data handling, modeling, or access to enormous data banks, their spectral photo interpretation, and so on, but no mention is made of the meticulous data collection, no matter how trying or boring the circumstances. The common practice of performing field work ahead of schedule often results in hastiness and fatigue which affect accuracy.

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*Strong words, but the author has often reviewed absolute cover data wherein the total cover of all plants, litter, bare ground, rocks, and mosses or lichens did not come very near 100 percent.

Yet a third reason is the lack of thoughtful data analysis which should accompany statistical summarization. No one is more aware of trends or anomalies evident from the data than the preparer, and it is his or her responsibility to formulate hypotheses and explore relationships. This is not strictly required and seldom preferred. For their part, regulatory agencies often have a reputation for measuring the adequacy of premine inventories "by the pound" and may lack the time or personnel to thoroughly evaluate all the data they receive. Thus, to the charge that premine vegetation inventories are discriminatory and punitive may be added the allegation that they are wasteful.

There is probably no way to require a specified level of data analysis via regulations or guidelines. The only hope is that regulatory personnel put a higher priority on scrutinizing submitted information and require more thoughtful and complete analysis. This could be accomplished by contracting this work or other work which would free them for this important task.

Another Approach

The final aim of revegetation is functional: community function and land use similar to premine conditions without any higher rates of site deterioration. Most data required by regulatory agencies are descriptive, although production data are certainly a measure of community function. It may be possible to shift from this reliance on descriptive information to a more functional approach.

For example, the data used to evaluate revegetation success in reference and revegetated areas could measure weight gains in livestock, actual wildlife use, crop production, and erosion losses over the bond period. If an acceptable level of functional equivalency were attained, revegetation would be successful, and descriptive data collections could be largely eliminated.

A reference area approach would be necessary so that comparisons would incorporate matched environmental conditions through time.

Due to time constraints, the selection of reference areas would have to be based on descriptive data, and this would require great care because reference area selection would influence all subsequent comparisons, as is now the case.

PART IV. CASE STUDY: THE CIRCLE WEST VEGETATION BASELINE AND MONITORING STUDIES

In 1974, Dreyer Brothers, Inc., a wholly owned subsidiary of Burlington Northern, Inc., notified the State of Montana that it proposed to develop a coal processing facility and mine in McCone County, Montana. The Montana Department of Natural Resources and Conservation (DNRC) entered into a contract with Dreyer Brothers, Inc., to perform certain environmental studies. The author conducted the subsequent vegetation baseline and monitoring studies, first as a DNRC employee and later as a consultant (Prodgers 1978, 1979, 1981, 1982).

The objectives of the vegetation baseline study were as follows (Prodgers 1978):

> The goal of this baseline study was to collect sufficient information describing the vegetation of the study area so that changes in vegetation can be detected, and further baseline and monitoring studies can be expeditiously carried out. This information which will eventually be used to evaluate the impacts of the proposed development was derived from data collected by:
>
>> Characterizing the vegetation of the area in a manner that serves the maximum number of needs and most concisely conveys information about the vegetation of any portion in the study area (Classification of vegetation into community types most nearly meets this requirement and other objectives, including the requirements of the Department of State Lands);
>>
>> Characterizing the average sites associated with the various community types;
>>
>> Comparing the community types with respect to species diversity;
>>
>> Mapping the vegetation of the study area and the range condition of the proposed mine area;
>>
>> Determing the productivity of the major community types of the proposed mine area; and
>>
>> Listing all plant species found in the study area and identifying any rare or endangered plants.

These objectives, with the exception of classification, are required for permitting in Montana. Vegetation baseline work was performed in 1976 and monitoring studies were conducted from 1977-1981 inclusive. Net above-ground primary production of communities was estimated from 1977-1981.

Canopy-coverage was estimated for the 1978-1981 period, and species diversity was calculated at various times using canopy-coverage data. A plant species list was compiled and annually updated and corrected.

Reconnaissance and Classification

Initially, a satisfactory vegetation classification system for the study area did not exist. A vegetation classification was deemed necessary for nearly all subsequent vegetation study, including vegetation mapping, reference area selection, and association of communities with site factors.

The classification was based upon data from 552 plots, which were sampled in 1976. Canopy-coverage (modified slightly from Daubenmire 1959) was estimated for 34.5 m^2 sample plots, and site information was simultaneously recorded. About half of the sample locations were selected prior to field work on the basis of aerial photographs, identifiable site factors, and geographic considerations. Other sample locations were chosen in the field to assure sampling of communities not distinguishable from aerial photographs. Thus, selecting sample locations combined subjective and objective (though certainly not random) elements. See Prodgers (1978) for a more detailed discussion of reconnaissance sampling.

Cluster analysis was used to portray community similarities and to guide classification. The unweighted canopy-coverage data were clustered by the pair group method and average linkage using Sorensen's (1948) index of similarity. The resulting dendrogram revealed both discrete community types and areas of gradation. Dendrogram interpretation was largely subjective.

Classification resulted in recognition of 27 community types and one phase containing 452 of the sample plots (82 percent). A larger number of samples might have resulted in recognizing more types or other classification revisions.

Community types were described in terms of plant species composition (average canopy-coverage and constancy), associated site factors, structure, and species diversity (richness or species density, Simpson index, and Shannon-Wiener index). The reader is referred to Prodgers (1978) for a more complete treatment of the topics briefly addressed here.

The test of any classification is how well it meets the needs of the user. The major uses of the classification were to: 1) provide a framework for describing and studying the vegetation of the study area; 2) aid the selection of reference areas; 3) evaluate wildlife habitat; and 4) aid in vegetation mapping. The use of the classification for vegetation mapping was probably the most demanding test of its validity.*

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*This classification may be useful to investigators attempting to devise a habitat type classification for the prairies of eastern Montana.

Vegetation Mapping

The vegetation of 11.5 square miles was mapped at a scale of 1:4,800 in 1977. The potential permit area was later expanded and approximately 20.5 additional square miles were mapped in 1980. Both 1977 and 1980 were dry years.

Field notes from these mapping efforts suggest that the classification worked quite well overall, especially when the size and diversity of the mapped area are considered. As expected, not every plant community in the mapped area was fit precisely by the classification, just as every reconnaissance community was not eventually incorporated into the classification.

Vegetation Mapping Technique

Ground truth information was collected for each section using a modified systematic approach. Each section was traversed at intervals of 100 yards or less and the appropriate community type for the communities traversed was indicated on a 1:4,800 topographic map with 10-foot contour intervals every 100 yards or less or whenever a distinguishable community boundary was traversed. In heterogeneous areas, these changes were abrupt and frequent.

When a plant community was not amenable to the classification, the relative abundance of the dominant species was indicated on the map. Community boundaries were indicated when possible.

Color infrared transparencies of the area taken in 1976 were enlarged to an average scale of 1:4,800. Plastic copies of the 1:4,800 topographic maps were aligned over these aerial photographs and the ground truth information was superimposed on the maps. A final transparent plastic sheet overlayed these information sources on a high-intensity light table in a semidark room. Mapping was thus done on the simultaneously combined basis of ground truth, topographic, and remote sensing information.

Difficulties in Mapping

The mapping was successful, but prairie vegetation patterns and gradients can be extremely complex, and at a scale of 1:4,800, great attention may be directed to detailed features of the vegetation. The following difficulties and limitations were noted.

1. Determining boundaries in broad coenclines, particularly in relatively undifferentiated lowlands where both community gradients and site factors change gradually. For accurate mapping, perhaps transitional areas should be mapped, but it is questionable how this would fit into the reference area approach.

2. Insufficient map resolution in some areas even at a scale of 1:4,800. Mapping units often contained several communities where the vegetation formed a mosaic unmappable at a scale of 1:4,800.

3. Mapping of areas greatly affected by drought and heavy grazing, often combined.

4. Determining the amount of variation allowable in a community similar in most respects to an identified community type, but differing significantly with respect to abundance of one or more species.

5. Mapping areas which had been cultivated at some time, often dating back many decades. These communities did not correspond to community types.

6. Mapping highly diverse areas where the soil has not stabilized, such as steep coulee banks and some badland/scabland areas. There is a high degree of randomness in the vegetation of these areas, and in some cases it may not be accurate to think of "associated species."

The fact that the classification was based upon data collected in a single year might also be considered a limitation.

Before leaving the topic of mapping, the author would like to make two points. First, the effort expended in vegetation mapping was out of proportion to its usefulness, which to date has been limited to some broad wildlife habitat delineations. This is possibly the result of the inordinately large area mapped. Second, after using well-timed panchromatic, true color, and color infrared aerial photography of high quality, the author is highly skeptical of allegedly detailed vegetation mapping which relies on photo interpretation at the expense of ground truth information. Many subtleties of vegetation in this area are not visible from the aerial imagery mentioned. However, others have found photo interpretation techniques to be completely adequate for mapping purposes (Shaver and Fisser 1973).

Production

Production estimation from this study has probably been more worthwhile than other monitoring components. At the same time, some limitations are evident, and other studies may benefit from identification of these limitations.

Thirteen major community types were identified for monitoring from the originally proposed mine area. Representative communities were selected, and sampling was initiated in 1977 with 25 plots per community. These communities consisted of 11 grass-dominated communities, a silver sagebrush/grass community, and a horizontal juniper/grass community in which conventional production estimation proved impractical. In 1978 and 1979, the number of plots sampled in each community was determined (using the previous year's data) to obtain a sample mean within 20 percent of the population mean at the 80 percent probability level. Due to the uncertainty of comparisons, a slightly higher level of precision was desired in 1980; the desired sample mean was to be within 20 percent of the population mean at the 90 percent probability level. In 1981, the standards were again raised to allow more certain comparisons and a correlation of production with available soil moisture. Communities for which soil moisture determinations were made were sampled for production to obtain sample means within 10 percent of the population means at the 90 percent probability level, while other communities were sampled to obtain sample means within 10 percent of population means at the 80 percent probability level. Some controlled grazing of exclosures showing significant litter accumulation was practiced in 1980 and 1981. Plant material was clipped to the point of origin of above-ground growth and oven-dried to constant weight at 70°C.

While data from all communities cannot be summarized here, two communities and three species have been selected as examples.

Variations in Annual Production

The magnitude of annual fluctuation in production can be startling (see Fig. 1).* Moreover, plant communities exhibiting similar production in some years can have quite different productions in other years, so the ranking of communities by production can change dramatically.

The picture of community production is complicatd by the individualistic behavior of dominant species within a community (Figs. 2 and 3). Tentative explanations of species behavior may be confounded or clarified by the behavior of these species in different communities (and of course on different sites, etc.). For example, Figures 4 through 6 demonstrate the effects of site, competition, and other environmental factors on the production of three grass species. The specific interpretation of these variations need not concern us here, but several implications should be considered:

1. Successful prairie plant communities exhibit a great deal of resiliency.

2. Species react individualistically to environmental conditions.

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*Due to graphic space limitations, species have been abbreviated using the first two letters from their genus and species.

Abbreviation	Scientific Name	Common Name
Agsm	*Agropyron smithii*	western wheatgrass
Agsp	*Agropyron spicatum*	bluebunch wheatgrass
Ansc	*Andropogon scoparius*	little bluestem
Bogr	*Bouteloua gracilis*	blue grama
Cafi	*Carex filifolia*	threadleaf sedge
Dist	*Distichlis stricta*	inland saltgrass
Stco	*Stipa comata*	needle and thread

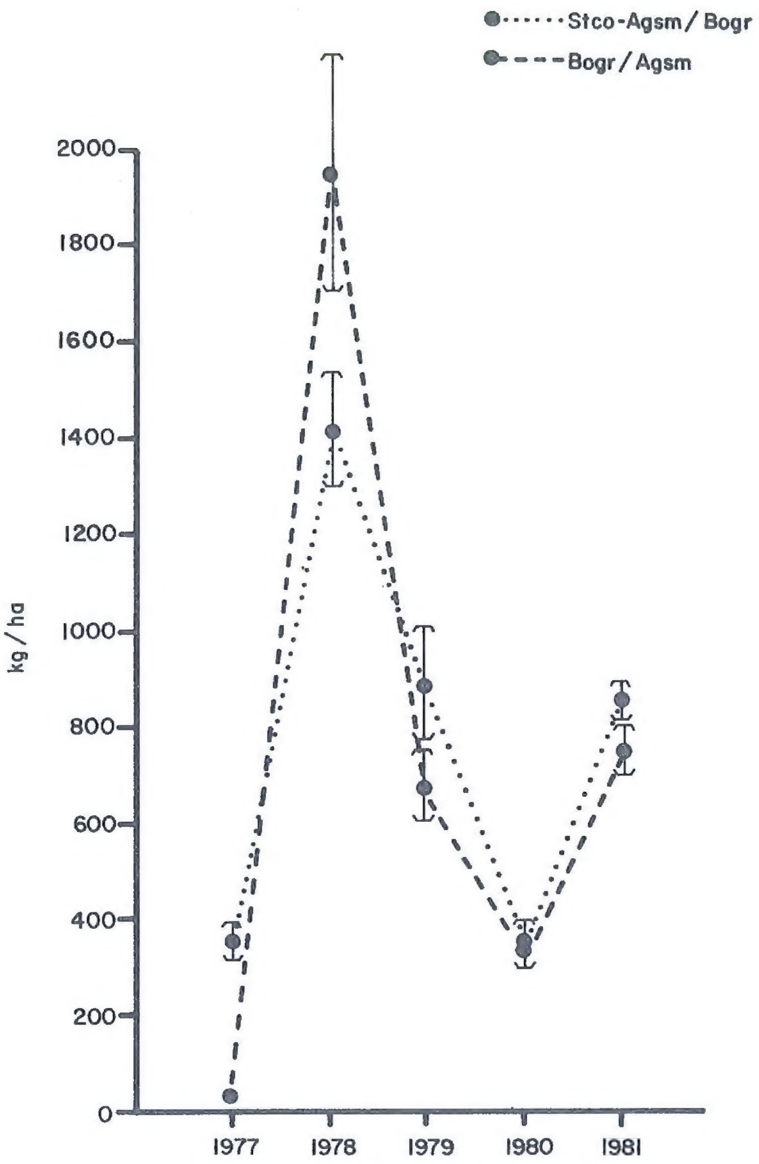

Figure 1. Net aerial primary production in two grass-dominated communities over a five-year period. (Means and 90% confidence limits shown.)

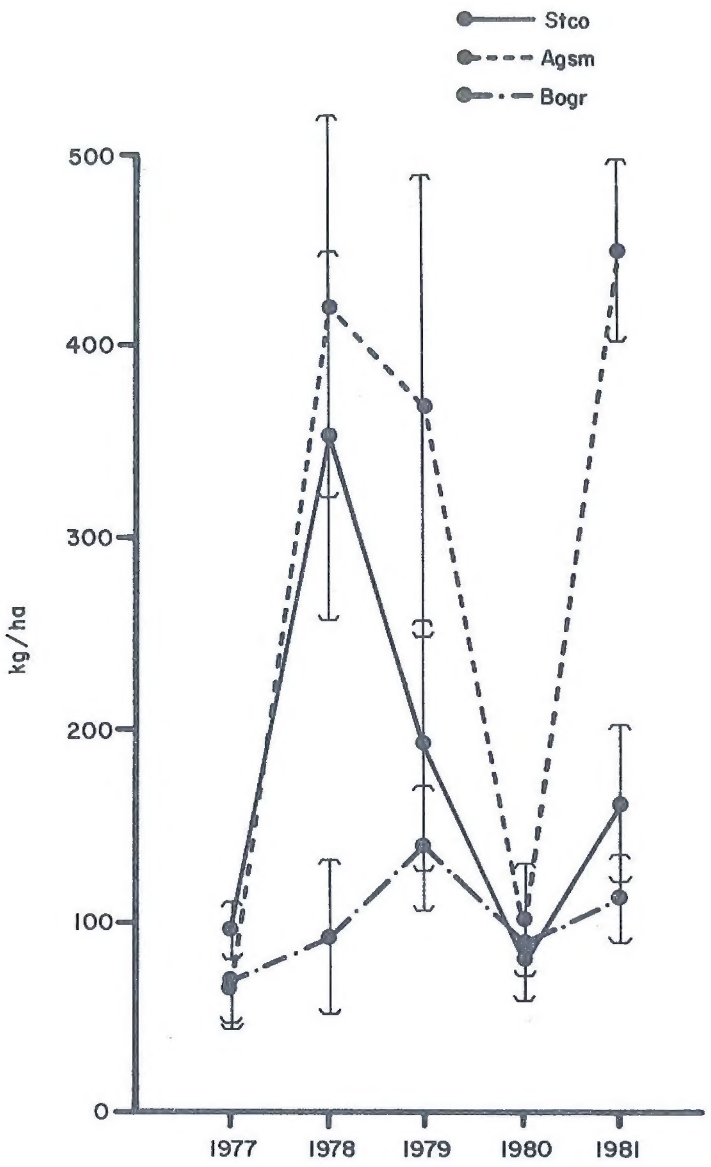

Figure 2. Net aerial primary production of dominant species of the Stco-Agsm/Bogr community over a five-year period. (Means and 90% confidence limits shown.)

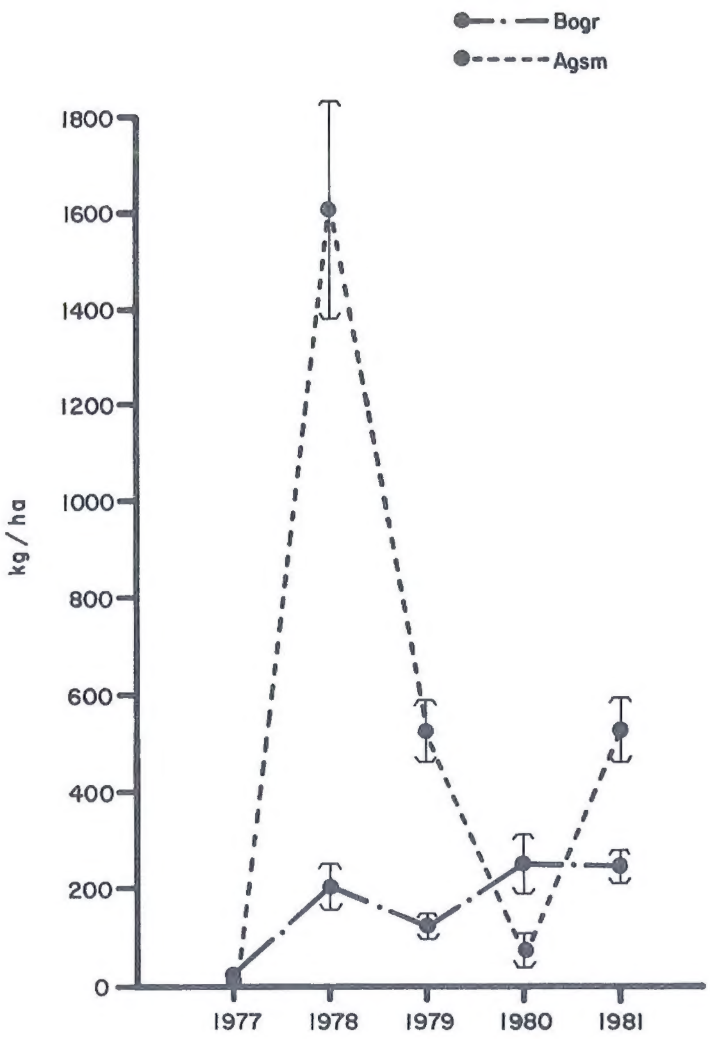

Figure 3. Net aerial primary production of the dominant species of the Bogr/Agsm community over a five-year period. (Means and 90% confidence limits shown.)

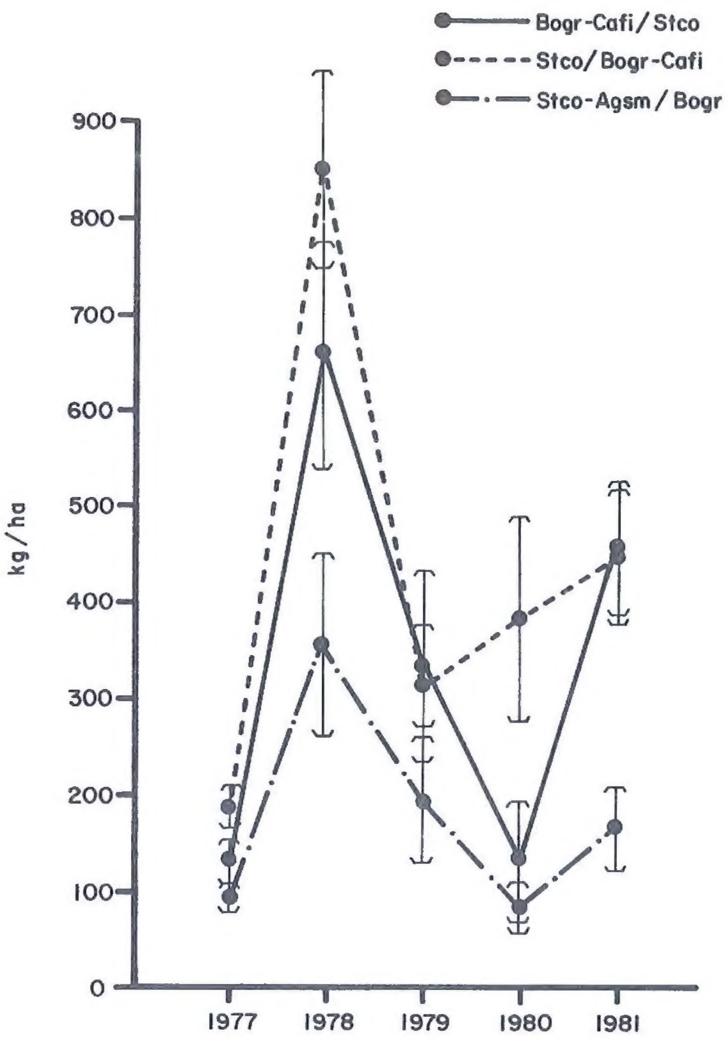

Figure 4. Net aerial primary production of Stipa comata in three communities over a five-year period. (Means and 90% confidence limits shown.)

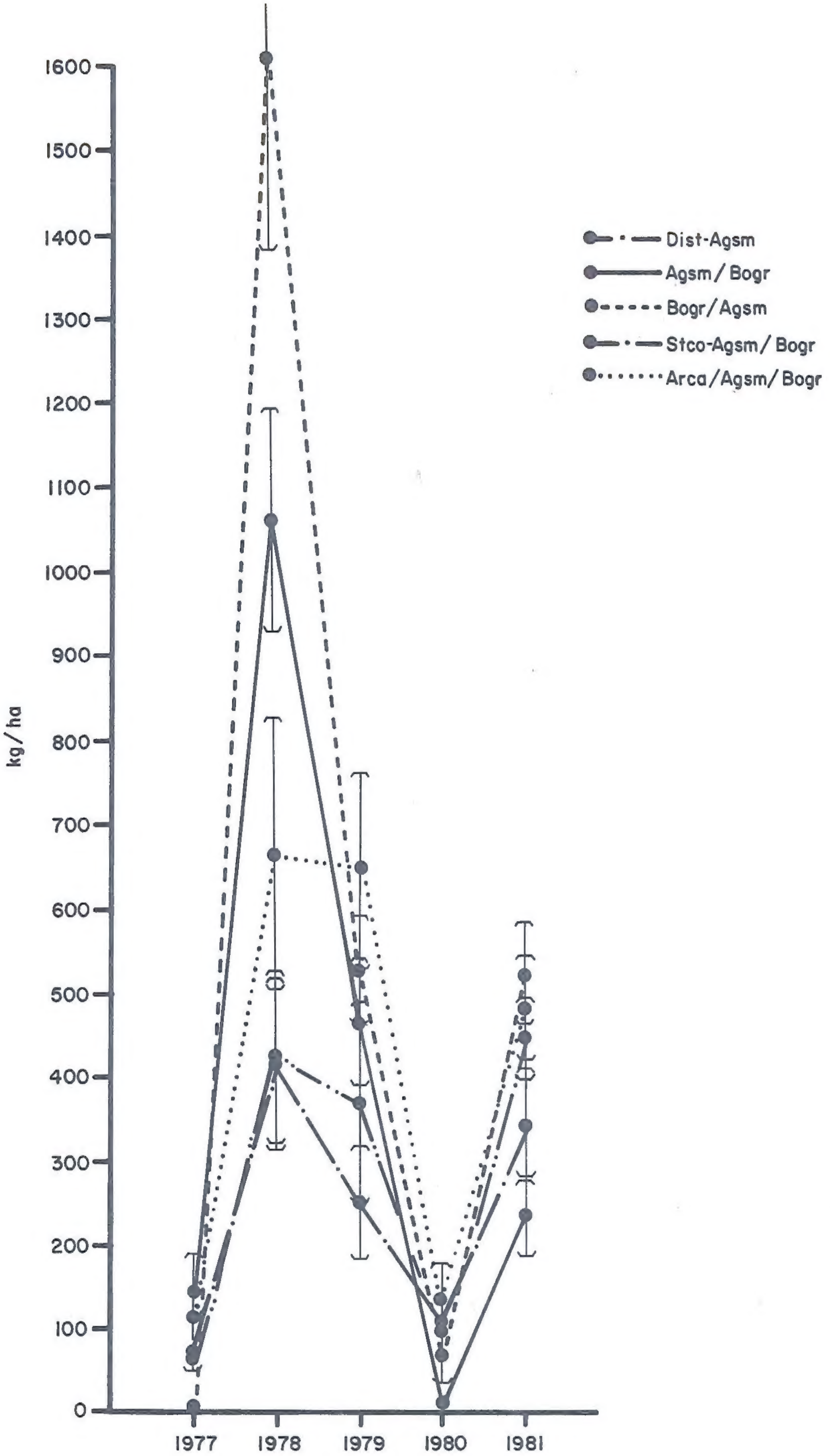

Figure 5. Net aerial primary production of Agropyron smithii in five communities over a five-year period. (Means and 90% confidence limits shown.)

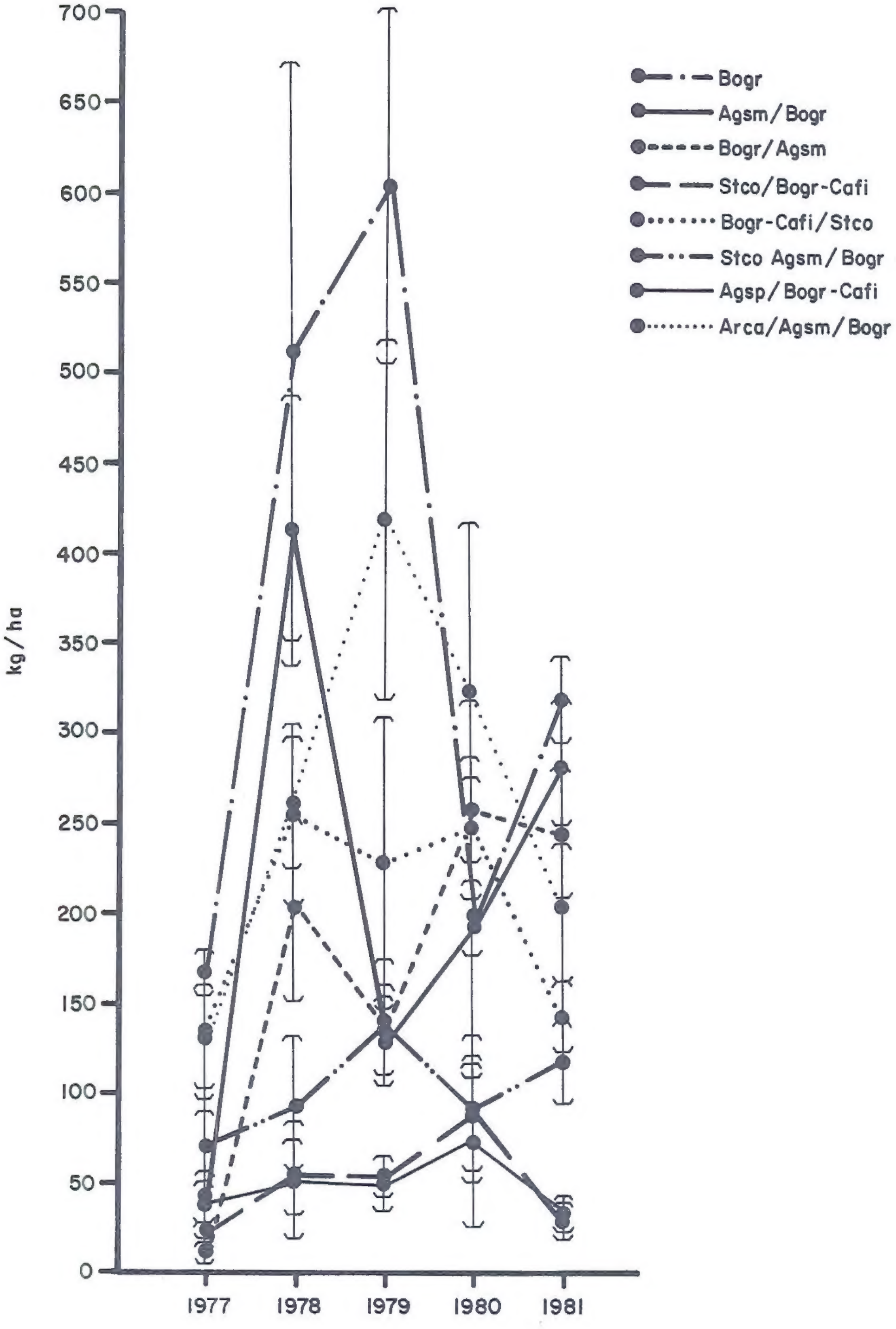

Figure 6. Net aerial primary production of Bouteloua gracilis in eight communities over a five-year period. (Means and 90% confidence limits shown.)

3. Quantitative plant measurements--at least those emphasizing the quantity of herbage produced--cannot be collected in a single or few years and taken to be representative of measurements taken in other years.

4. Annual production available to herbivores fluctuates to a greater extent than is often recognized.

5. Climatic effects on production can be significantly enhanced or ameliorated by other factors, such as site factors and community species composition.

6. Classifications which are based upon the relative abundance of shared dominant species may result in communities being assigned to different types in different years.

7. Similarly, vegetation maps portraying actual vegetation may be subject to revision due to annual changes in addition to long-term trends.

8. Range condition determinations can be greatly affected by variations in production which are not the result of grazing.

9. Long-term studies are necessary to portray production dynamics.

To illustrate some effects of climatic variations on range conditions, two exclosures in areas mapped as soil series (not soil complexes) were evaluated in strict accordance with the SCS Technicians' Guide to Range Sites, Condition Classes and Recommended Stocking Rates in Soil Conservation Districts of the Sedimentary Plains of Montana, 10-14" Precipitation Zone.

The Bogr/Agsm exclosure (silty range site) rated a solid fair condition in 1977, a year in which grasshopper damage may have lowered the rating. In 1978 and 1979, the protected vegetation appeared to be in excellent condition with about 90 percent of the theoretical climax community composition present. In 1980, a year of drought but few grasshoppers, the condition seemed to return to fair; about 30 percent of the theoretical climax was present.

The Agsm/Bogr exclosure occupies a clayey range site. This exclosure rated good (almost excellent) condition in 1977, 1978, and 1979 despite great variability in production values. However, in 1980, the condition slipped to poor, with less than 15 percent of the theoretical climax present. Changes of this magnitude under exclosure conditions indicate a need to incorporate the effects of climatic fluctuations on both early and late successional vegetation into range condition estimates.

Shortcomings in Production Study

Climatic and Soil Moisture Measurements

For an understanding of production dynamics, the identification of what causes observed fluctuations in annual production is highly desirable; a quantitative or mathematical description is preferred. The author believes that available soil moisture was the chief determinant of production in this study, as has been observed in other similar studies (Smoliak 1956, Reed and Peterson 1961, Rogler and Haas 1946, Coupland 1959, Mather 1959, Clarke *et al*. 1943). However, such measurements as well as on-site precipitation records were not collected until 1981. Elaborate meteorological stations in the study area were repeatedly planned, but they never materialized, and the usefulness of the data is severely limited by the lack of climatic and soil moisture data.

Accuracy

Estimating production by means of a single harvest (peak standing crop) undoubtedly resulted in a significant underestimation of net areal primary production. It is also probable that the magnitude of variations was greater than is shown due to the greater contribution in wet years of early maturing perennials (e.g., *Poa sandbergii*, *Koeleria cristata*) and annuals (e.g., *Festuca octoflora*). Annuals which were nearly absent in drought years attained significant production in wet years. Many of the communities sampled contained dominant species exhibiting extremely divergent phenologies. A few did not, and peak standing crop estimation was probably adequate for these communities.

Precision

As Figures 2 through 4 illustrate, the production of dominant species is critical to an understanding of community production dynamics. While the cost of taking enough samples to obtain high precision with respect to dominant species may be prohibitive, a goal of obtaining a community production sample mean within 20 percent of the population mean may not be adequate even to evaluate production of the same community through time. Almost surely this level of sampling will not allow determination of a reliable mathematical relationship between moisture and production or production comparisons at the dominant species level. Adequate sampling precision for most purposes was probably obtained in 1981.

Length of Study

The discontinuance of this study prior to sampling in 1982 is understandable in light of uncertain development plans and a pronounced lack of encouragement from the Montana Department of State Lands. Nevertheless, data from 1982, a year of relatively abundant precipitation following the dry years of 1980-1981, might have contributed a good deal of information about the plant communities and species studied.

To the layman--or the executive who is forced to budget for environmental studies--5 years of production data may seem redundant. In fact, data from 1982 might have greatly increased the conclusiveness of the study. Would some communities of low diversity (blue grama, inland saltgrass) prove to be more stable than a community of high diversity (little bluestem) which appears to have undergone significant change as a result of drought? Which species will show the quickest and most complete recovery? What new lessons can be learned about population dynamics and the effects of climate? Reliable long-term studies of natural and seminatural communities are important to determine what can reasonably by expected from revegetated communities and to clarify the relationship between descriptive and functional parameters.

Canopy-Coverage

Beginning in 1978 and continuing through 1981, canopy-coverage was estimated in the communities chosen for monitoring using twenty 20-cm x 50-cm frames. Canopy-coverage was estimated using the polygon technique of Daubenmire (1959), but percent absolute coverage was estimated as accurately as possible and cover classes were not used. Two sets of 10 frames each were sampled in each community. These were oriented along topographic contours, and none of this area has ever been clipped.

Canopy-coverage has some advantages for monitoring, including sampling speed, easy collection of data (by species) for nonabundant species, and sampling of the same plots through time, which greatly facilitates comparisons. However, canopy-coverage is often not as sensitive an index of species abundance as production.

Variation In Community Similarity Based Upon Canopy-Coverage

The canopy-coverage descriptions of communities are often compared using some similarity index or formula, usually Sorensen's (1948). Some applications of similarity calculation are: classification, comparison of communities with average community type values for reference area selection, and comparison of premine or reference vegetation with the vegetation resulting from revegetation efforts.

Tables 3 through 5 portray the internal similarity (Sorensen 1948) of three communities sampled for canopy-coverage over 4 years by the same investigator. Two of these sample communities have been used earlier in a discussion of production, and the third was selected to show the effect of a shrub dominant, which turns out to be minimal. Sample frame locations were the same each year, and time of sampling varied by a few weeks at most.

Tables 3 through 5 suggest that community similarities of roughly 70 percent might be considered quite high for most purposes when between-year data are used. When frame placement, time of sampling, and investigators vary, or when different communities are compared, significantly lower similarity values may result. Comparisons based upon life-form or other species grouping would tend to yield higher similarity values than comparisons based upon species.

TABLE 3. SIMILARITIES (PERCENT) OF THE STIPA COMATA-AGROPYRON SMITHII/BOUTELOUA GRACILIS COMMUNITY OVER A 4-YEAR PERIOD.

	1978	1979	1980	1981
1978	100			
1979	76	100		
1980	70	76	100	
1981	67	83	84	100

TABLE 4. SIMILARITIES (PERCENT) OF THE BOUTELOUA GRACILIS/AGROPYRON SMITHII COMMUNITY OVER A 4-YEAR PERIOD.

	1978	1979	1980	1981
1978	100			
1979	81	100		
1980	64	81	100	
1981	63	79	80	100

TABLE 5. SIMILARITIES (PERCENT) OF THE ARTEMISIA CANA/AGROPYRON SMITHII/BOUTELOUA GRACILIS COMMUNITY OVER A 4-YEAR PERIOD.

	1978	1979	1980	1981
1978	100			
1979	78	100		
1980	73	80	100	
1981	72	83	87	100

Canopy-Coverage and Production

Production and canopy-coverage (or some cover measurement) are probably the most frequently used vegetation parameters for premine inventories. These measurements tend to show similar trends, but production often gives a picture of higher variation and the two measurements need not result in analogous conclusions.

In the following comparisons of canopy-coverage and production estimates, the reader should note that comparisons are limited by the arrangement of canopy-coverage frames in two sets of 10 frames, which may be treated as only two samples. This limitation is somewhat mitigated by averaging data from three to eight communities.

Figure 7 portrays average production and canopy-coverage of Bouteloua gracilis in eight communities over a 4-year period. Bouteloua gracilis is a perennial warm-season shortgrass which usually reproduces vegetatively and is often mat-forming. It is relatively drought tolerant, often surviving drought through dormancy, and may quickly increase in abundance following drought. Resistance to grazing and trampling is high and competitive ability under conditions of adequate soil moisture and protection from grazing is rather low. Figure 7 shows a good visual correlation between production and canopy-coverage of Bouteloua gracilis. Highest average production was 1.1 times the 4-year average while highest canopy-coveage was 1.2 times the 4-year mean. Lowest average production was 0.8 times the 4-year average while lowest canopy-coverage was 0.7 times the 4-year mean. Because of its extreme shortness in dry years, Bouteloua gracilis is difficult to clip and subject to underestimation of production. Production and canopy-coverage seem to be about equally sensitive abundance indices of Bouteloua gracilis.

Figure 8 portrays average production and canopy-coverage of Stipa comata in three communities over a 4-year period. Stipa comata is a caespitose perennial mid-grass and is usually considered a cool-season grass, although it may be considered intermediate in this respect (Munshower and De Puit 1977). Reproduction is by seed. Drought tolerance and competitive ability are moderate. Susceptibility to grazing is above average before awns develop and after seed drop, but some protection is afforded by the formidable seeds and awns when present. Figure 7 shows a general correlation between canopy-coverage and production, but production shows greater yearly variation. Highest average canopy-coverage is 1.3 times the 4-year average, whereas highest production is 1.7 times the 4-year average. Lowest average canopy-coverage is 0.8 times the mean, while lowest production is 0.5 times the mean. The lower sensitivity of canopy-coverage is due to the fact that, in dry years, Stipa comata individuals consist of a reduced tuft of basal leaves and a few stems, usually weakly ascending. A rather large polygon is formed when the plant is viewed from above and the stem tips are (imaginatively) connected. In years when more moisture is available, the basal leaves are larger and more numerous (usually with no effect on canopy-coverage) and the stems are more numerous--but often more ascending. The polygon formed by (imaginatively) connecting stem tips is not increased in proportion to the increase in production.

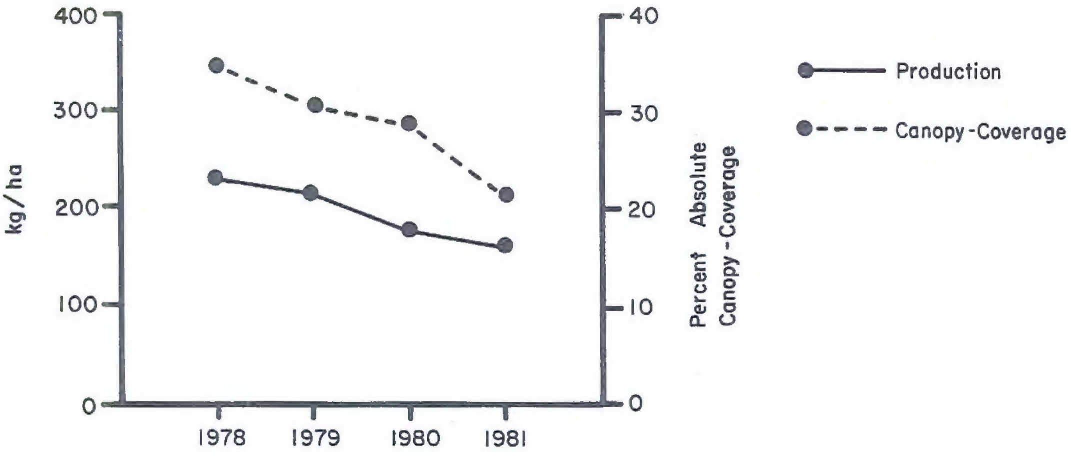

Figure 7. Average annual production and canopy-coverage of Bouteloua gracilis. (Means based on data from eight communities shown.)

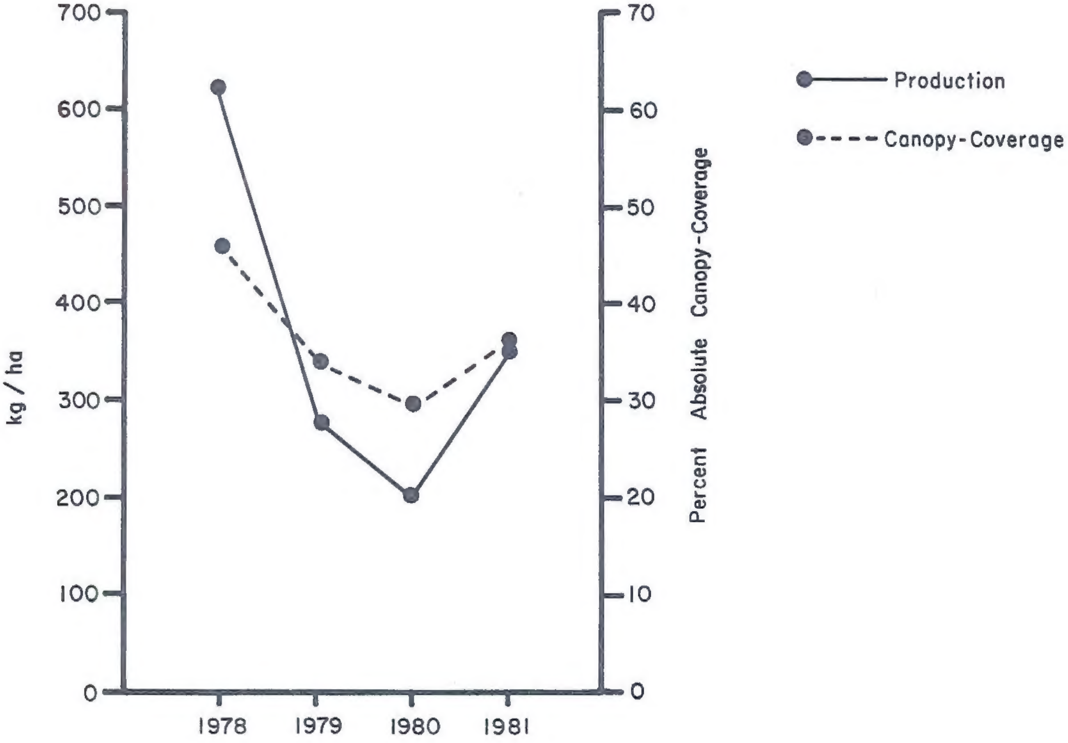

Figure 8. Average annual production and canopy-coverage of Stipa comata. (Means based on data from three communities shown.)

Figure 9 portrays the average annual production and canopy-coverage of Agropyron smithii in five communities over a 4-year period. Agropyron smithii is an erect, single-to-few-stemmed, rhizomatous, cool-season mid-grass. Tolerance to drought is low and palatability is rather high. Competitive ability under favorable conditions is quite high, and the availability of moisture greatly affects abundance.

Figure 9 reveals a visual correlation between average annual production and canopy-coverage of Agropyron smithii from 1978 to 1980, although fluctuations in production are much greater than variations in canopy-coverage.* Over this period, highest average canopy-coverage was 1.4 times the 3-year average, while production was 1.8 times the average. Lowest canopy-coverage was 0.5 times the 3-year mean, whereas lowest production was 0.2 times the 3-year mean.

In 1981, the visual correlation between canopy-coverage and production of Agropyron smithii was refuted (Fig. 9). While canopy-coverage increased only slightly from the 1980 level, production increased roughly fivefold. It is unlikely that this result is a sampling anomaly as the only suspect measurement is an unusually high Agropyron smithii canopy-coverage value in one community in 1980.** One hypothesis is that the drought of 1980 resulted in the death of many Agropyron smithii individuals, and in the modestly improved conditions of 1981, a smaller number of individuals attained a larger size than would have been the case if density was higher. For a given level of production, canopy-coverage of frames containing fewer but larger individuals would be lower than for frames containing more numerous but smaller individuals.

Species Density

The Circle West vegetation studies do not emphasize species diversity calculations. The baseline report (Prodgers 1978) shows the average species richness (sometimes called species density), Simpson index, and Shannon-Wiener index for the community types identified. Monitoring reports present data for species richness only.

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*The canopy-coverage of plant species morphologically similar to Agropyron smithii can be difficult to estimate accurately, at least for the author. In this study, the canopy-coverage of Distichlis unispicata in two communities appears to have been underestimated by about 10 percent in 1979 (DNRC 1981).

**Deleting data from that community, the average canopy-coverage of Agropyron smithii varied about 4 percent from 1980 to 1981--a modest increase still far below the expected canopy-coverage (around 20 percent) which would be suggested by the production data.

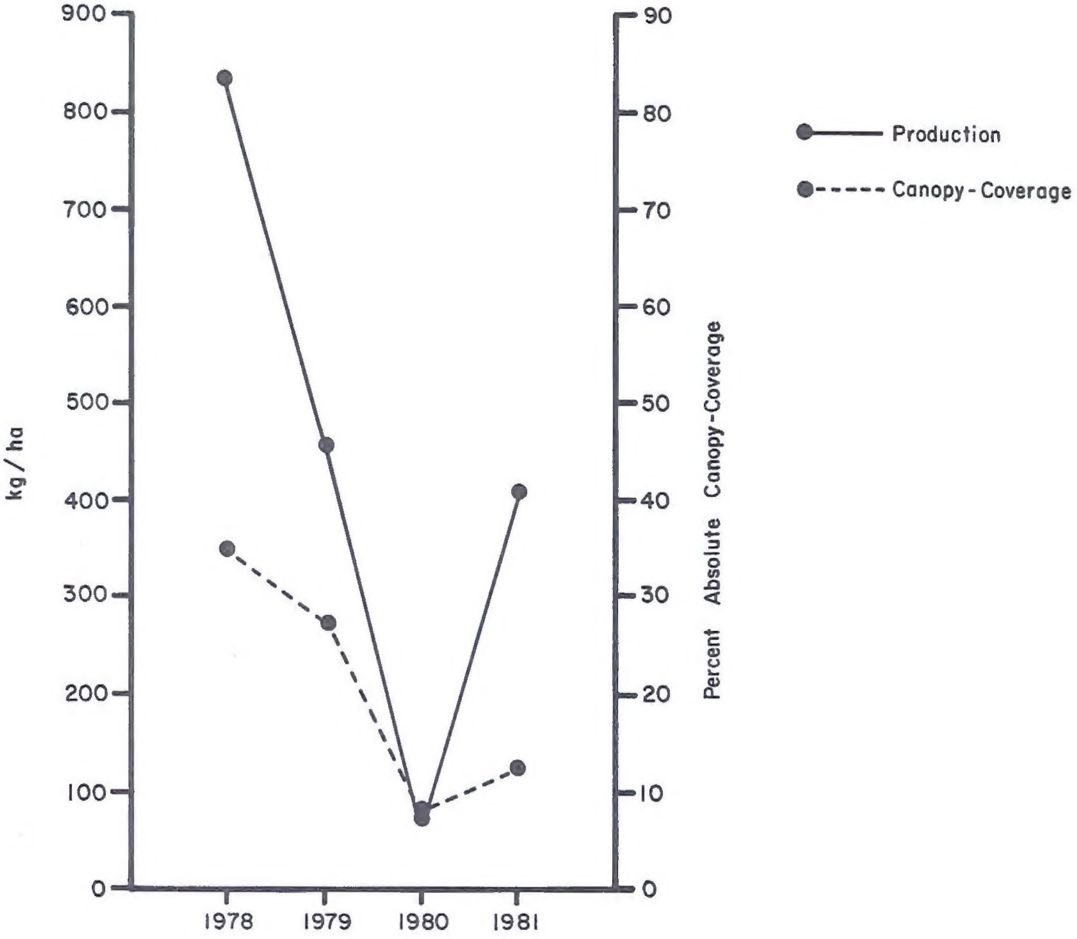

Figure 9. Average annual production and canopy-coverage of Agropyron smithii. (Means based on data from five communities shown.)

Figures 10 through 13 portray community production and species density for four grass-dominated communities. Production is taken to represent community function. The *Distichlis stricta* community of Figure 10 has an extraordinarily low species density and would rate very high on the Simpson index and very low on the Shannon-Wiener index. *Distichlis stricta* communities in the study area are resistant to climatic fluctuations, heavy grazing, and crushing. The yearly increase in production is attributed to protection from grazing coupled with rather constant soil moisture availability.

The *Bouteloua gracilis* community of Figure 11 has a rather low species density and would rate low on the Shannon-Wiener index, high on the Simpson index. This community, located near water at the site of a one-time prairie dog colony, has shown the ability to endure and recover from drought, grasshopper infestation, trampling, and heavy grazing by sheep, cattle, and prairie dogs.

The *Agropyron spicatum*/*Bouteloua gracilis*-*Carex filifolia* community (Fig. 12) exhibits an above-average species density and would rate above average on the Shannon-Wiener index and below average on the Simpson index when compared with other upland communities in the area. *Agropyron spicatum* approaches the eastern limit of its distribution in this area. This community, while restricted to certain sites, appears to be well adapted to the vicissitudes of the environment, but no more so than the less diverse communities previously mentioned.

The *Andropogon scoparious* community (Fig. 13) exhibits a very high species density but would rate rather high on the Simpson index and somewhat low on the Shannon-Wiener index, although these values have meliorated in recent years. *Andropogon scoparius* is near the northwestern extent of its distribution in this area. In this community, *Andropogon scoparius* appears to have been more harmed by the drought of 1979-1980 than any other major grass species. For example, 95 percent of community production in 1977 (of 840 kg/ha) was contributed by little bluestem, but only 56 percent of community production in 1981 (of 738 kg/ha) was contributed by little bluestem. This community seems to exhibit functional resiliency, but species composition is far from stable.

Figures 10 through 12 might be interpreted as showing that the characteristics of the dominant species and how well they are adapted to their environment are more important to community function than diversity. Figure 13 indicates that community function may be maintained despite reduced abundance of the community dominant in a community characterized by high species diversity, but also a high Simpson index and low Shannon-Wiener index. There is little support for the notion that communities of high diversity, as commonly measured, are better adapted to the prairie environment than communities of low diversity.

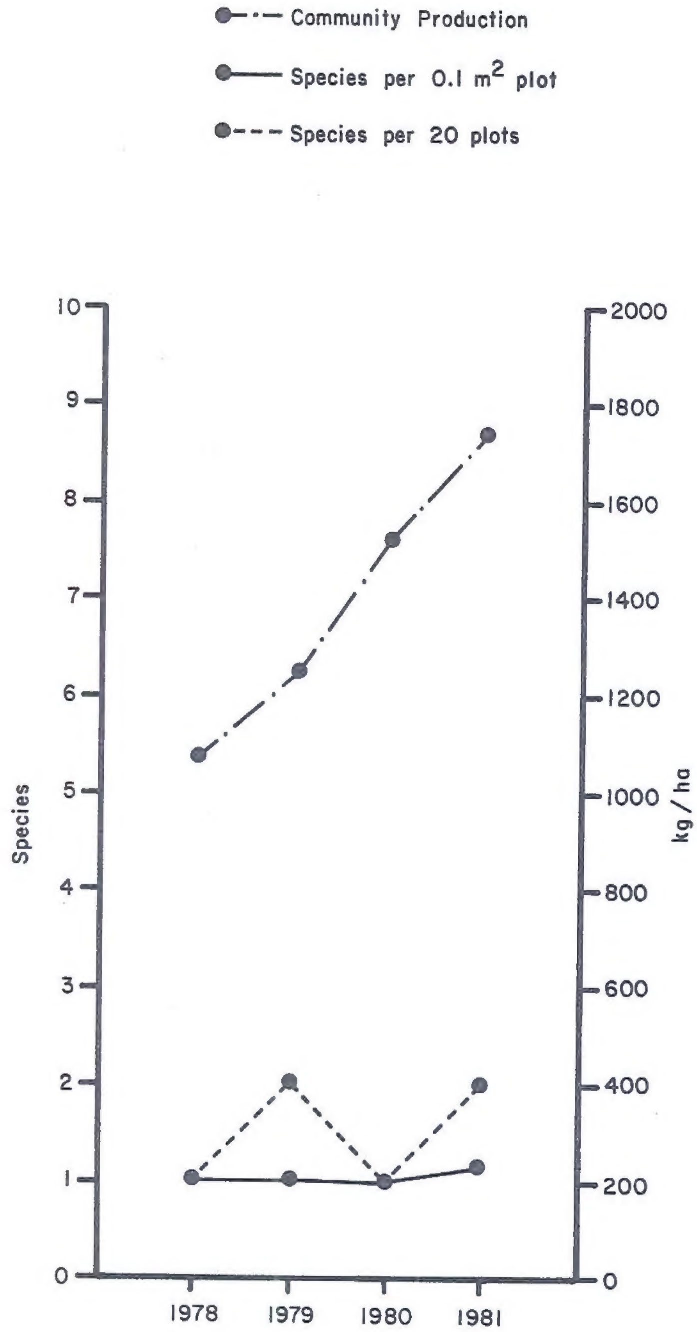

Figure 10. Average annual production and species density of the Dist community over four years.

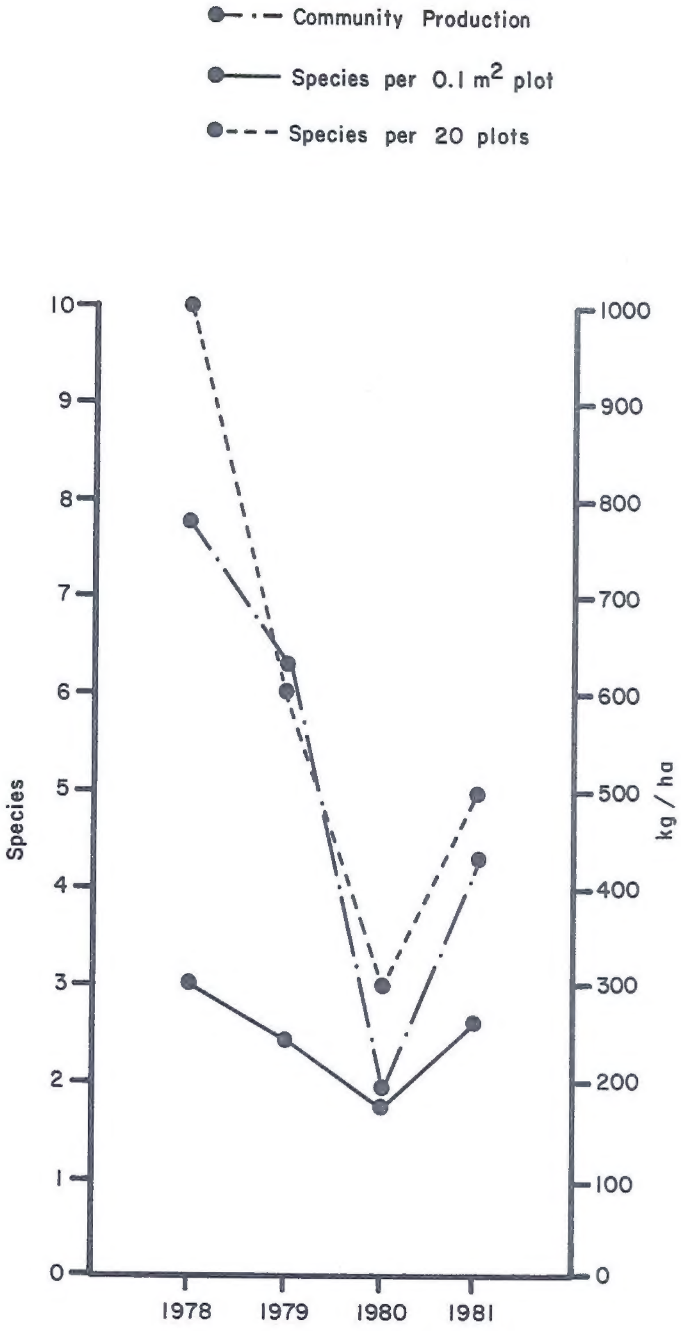

Figure 11. Average annual production and species density of the Bogr community over four years.

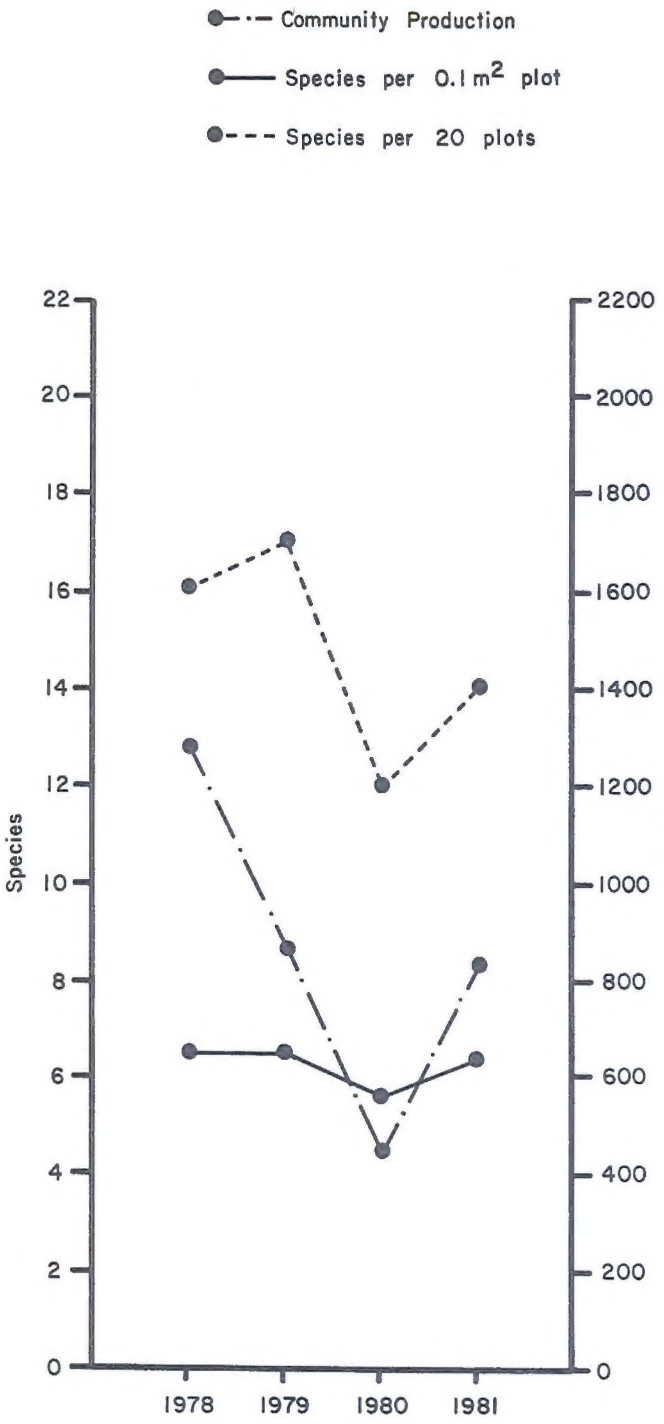

Figure 12. Average annual production and species density of the Agsp/Bogr-Cafi community over four years.

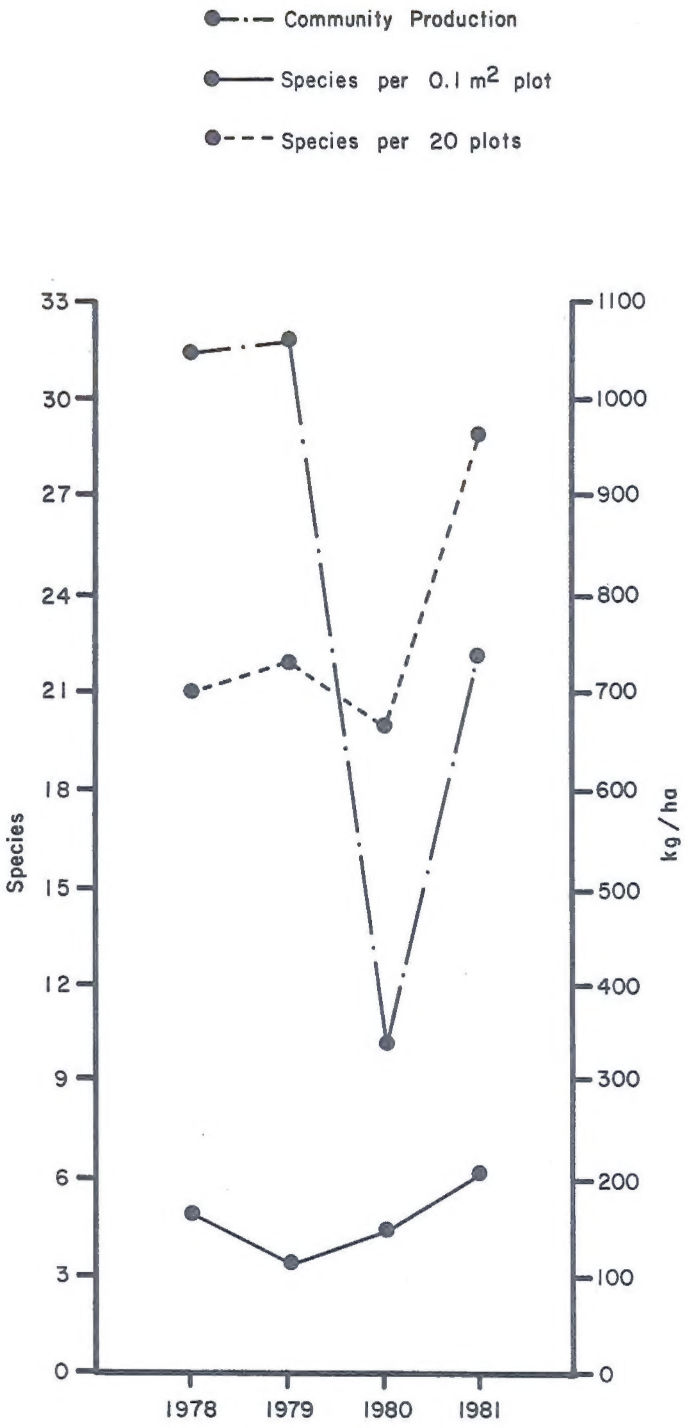

Figure 13. Average annual production and species density of the Ansc community over four years.

Species List

A list of vascular plant species was compiled beginning in 1976 and revised annually through 1981. Voucher specimens were collected. While taxonomic certainty is necessary for all phases of vegetation study, the compilation of a species list places undue emphasis on collection and identification of uncommon species of questionable functional importance. Overall, the effort that went into the species list has been of limited use.

A specimen of a species of watercress identified as "threatened" was collected, but the status of that species was subsequently changed to "species whose status is insufficiently known and needs more study." The presence of a species of bulrush indicated a range extension. Thus, the species list may someday make a very minor contribution to an atlas of the flora of eastern Montana. It is questionable whether it was worth the effort.

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VEGETATION INVENTORIES IN THE FORT UNION REGION

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INTRODUCTION

Increased development of nonrenewable natural resources is exerting impacts on the vegetational resources of the Fort Union Region. Hydrocarbon/mineral exploration and extraction, electricity and synthetic fuels production, and the development of transportation systems are altering the historic land use patterns and the allocation of the vegetational resource. Historically, land use in the Fort Union Region has been dominated by crop and livestock production. The agricultural demand for land and the vegetational resource continues to expand and conflicts at certain times and in certain areas with nonrenewable resource development.

State and Federal agencies have been required by law to formulate policies that maximize the long-term productivity of resources and minimize the environmental impacts. To fulfill the legal mandates associated with certain types of resource development, it has been necessary to acquire data on various parameters of plant ecology.

It is the intent of this paper to review the methods and philosophies followed by researchers in the Fort Union Region. Emphasis will be placed on Montana studies and Montana laws. Because coal mining and exploration currently exert the dominant demand for resources in the Fort Union Region, much of the discussion will focus on baseline data acquired for sites of proposed or existing mines.

VEGETATION STUDY DESIGN AND PHILOSOPHY

Since the establishment of the National Environmental Policy Act (NEPA) and similar State laws, a new type of resource inventory has been conducted which focuses on the relationship between decisionmaking and the natural environment. This type of inventory has been termed a baseline study. Baseline studies are conducted to qualitatively and quantitatively identify and describe the vegetational resource of a given area. Data acquired through baseline studies are used in the planning and impact assessment process before a project is initiated. The data are also used to define appropriate mitigation measures and to design future programs to monitor the accuracy of predictions and the effectiveness of mitigation.

States (1978) points out that since the inception of NEPA much baseline information has been gathered which is little use to decisionmakers, and even the useful information is often ineffectively used in the decisionmaking process. He stresses that a holistic approach should be taken in the design and execution of baseline studies, and that the following points are crucial to integrating useful data into the decisionmaking process:

1) The ecological study must be timed so as to maximize the use of data by decisionmakers.

2) Integration and interpretation of data between the various study disciplines are essential. Biologists, for example, must be cognizant of

engineering and hydrological information to clearly focus on certain biological predictions.

3) To the extent possible, data acquired should be statistically verifiable and be useful in separating man-induced from natural occurring biological changes.

With the previously listed general points in mind, let us consider more specifically how baseline studies are designed and conducted in response to proposed coal strip mining. The Montana Strip and Underground Mine Reclamation Act and guidelines, as approved by the Office of Surface Mining, describe suggested methodologies which should be followed to comply with the Act. The guidelines specify that the objectives of a baseline vegetation inventory are to provide:

1) A vegetation map which delineates community types based on two or more dominant species. Dominant species are those which by structure, number, or coverage have the greatest functional influence on the type.

2) A narrative describing the community types by listing associated species and discussing environmental factors controlling or limiting the distribution of species. Current condition and trend shall be discussed for each community type or portion thereof if significant.

3) A correlation and explanation of the relationship between plant community and soil types.

It is presumed that guidelines are formulated to help insure that data collected will satisfy the needs of resource managers/decisionmakers. It is also assumed by data gatherers and decisionmakers that the methods used to collect and analyze data reflect a certain level of ecological or scientific sophistication. The level of science that is involved with the design, execution, and utilization of baseline studies is not, however, clearly evident in the law or guidelines.

Because baseline studies are a relatively new concept, based on the amalgamation of science and law, it is not clear where science stops and the law begins. It is important to clearly understand which areas of the law or guidelines are based on bureaucratic necessity and which are based on sound ecology. In this spirit, I will discuss aspects of baseline study design which seem to be guided more by bureaucracy than by ecology.

Typal Community Versus Continuum Concept

The philosophy and approach dictated by the guidelines reflect certain ecological assumptions which are subject to scientific debate. The assumption that plant communities occur as observable, measurable, discrete assemblages of plant species, which predictably repeat themselves across the landscape and reflect the net influence of past and current environmental influences, is sometimes questioned. Some prominent ecologists contend that vegetation does not occur in discrete plant communities which are predictable, repeatable, and subject to mapping.

It is the divergence of view on the basic nature of plant communities which has inspired some plant ecologists to align themselves philosophically with either the Daubenmire typal community approach (Daubenmire 1966) or the continuum approach (Bray and Curtis 1957, McIntosh 1967).

Daubenmire contends that associations of plant species, particularly at climax successional status, predictably appear throughout the landscape where environmental conditions repeat themselves. Therefore, discrete groups of plant species with similar responses to environmental determinants can be visually discerned, measured, and mapped in a reliable and consistent manner.

The proponents of the continuum concept reject the notion that typal communities exist and assert that plant species occur throughout the landscape as a compositional gradient. The reason that no two plant species have identical rates of distribution, genetic composition, environmental tolerance, or botanical range. Thus, they concluded that because biological systems vary in composition continuously in time and space, these systems are not amenable to organization into discrete, mappable units.

Although the question of whether plant communities exist as discrete entities may seem like a largely academic argument, it has implications for biologists and regulatory agencies. Large amounts of time and money are committed to studying and mapping vegetation based on the assumption that plant communities can be mapped and quantitatively described. It is tacitly assumed that if a number of qualified plant ecologists conducted independent studies that similar results will be obtained in regard to community identification and mapping. I know of no field study where the reliability of community identification and mapping has been tested using independent investigators.

It has been my experience on a variety of studies throughout the Fort Union region that plant communities vary tremendously in regard to their relative discreteness and ease in mapping. In some locations where landforms and topography are distinct and where most of the area is near or at climax successional status, it is visually apparent, whether viewed from the ground or on aerial photographs, that certain plant communities predictably occur as more or less discrete and mappable entities. On sites where landforms are not readily distinguishable or where disturbances have altered the climax status, it is a practice in ecological legerdemain to identify and map the mosaic of plant communities that exist. In all cases where plant communities are mapped, heavy bias is placed on the distribution of visually dominant species. Often one visually dominant species dictates the mapping unit boundary. Inevitably, a certain amount of subjectivity is involved with plant community identification and mapping, making it somewhat of an artform as well as a scientific endeavor.

In an attempt to eliminate some of this subjectivity, statistical techniques have been devised to compare and separate plant communities. Multivariate analyses such as ordinations (Bray and Curtis 1957) and cluster analysis (Mueller-Dombois and Ellenberg 1974) have been used to classify plant communities on a numerical or quantitative basis.

Prodgers (1978) used a cluster analysis to construct a dendrogram which graphically depicted the quantitative relationsips between the stands sampled. After completion of the dendrogram, the preliminary classification was discussed with local experts and compared with published studies involving classifications or recognition of community types. Prodgers wrote:

> As a result modifications were made in the classification, but the dendrogram was always the frame of reference for any revision. Multivariate analysis did not, however, supplant the ecologist, whose interpretation and understanding of the phytocoenosis finally determined the classification.

VTN (1977) also used multivariate techniques to analyze plant communities. Different plant communities were distinguished by information-analysis utilizing an agglomerative strategy and centroid sorting (Williams *et al.* 1966). The information-analysis was then used as a basis for constructing a dendrogram. The initial groupings were modified with regard to literature accounts of communities and visual differences or similarities that would facilitate field recognition. However, stands were combined on the basis of visual factors which did not have substantial similarities in canopy coverage and frequency.

Olson-Elliott and Associates (OEA 1981b) analyzed quantitative vegetation data following techniques described by Mueller-Dombois and Ellenberg (1974). Based on similarity values, 196 stands were used to construct a dendrogram. Seven groupings of the dendrogram were similar to seven of the twelve community types identified on visual characteristics alone, whereas the other five community types were intermixed with the remaining dendrogram groups. The community types which were not similar to the dendrogram groupings were dominated by the most common species of the study area. Communities dominated by *Stipa comata*, *Bouteloua gracilis*, *Agropyron smithii*, and *Artemisia tridentata* were not distinguishable using the objective totally quantitative statistical techniques.

Mueggler and Stewart (1980) utilized ordination techniques (Bray and Curtis 1957) and cluster analyses (Sokal and Sneath 1963) to assist in a grouping of sample stands. They found that these quantitative techniques were of limited value for grouping sample stands into communities. Mueggler and Stewart wrote:

> We believe that the relatively few species exerting a potentially dominant role as expressed by a combination of morphology and amount of canopy should be stressed in the development of a meaningful classification. The importance of the potentially dominant role of these species appeared to be overshadowed in our ordination and

> cluster analyses by the great variation in presence and cover of minor species. The large variability of the many forb species especially appeared to overshadow basic similarities and dissimilarities inherent in the graminoid and shrub components which could be detected otherwise.

One study where statistical methods were successfully used to classify vegetation was conducted by Thilenius (1972). This study was conducted in the Black Hills of South Dakota to classify deer habitat in the ponderosa pine forest. By integrating vegetational, soil, and site characteristics, 100 stands were grouped into 13 habitat units using similarity coefficients to construct a dendrogram. Deer use of these habitat units was then studied to rank relative seasonal importance of the habitat units.

Based on the limited success in applying quantitative, objective methods to determine classification of plant communities, it could be concluded that strictly quantitative, statistical approaches are not acceptable to many plant ecologists. The primary reason for this seems to lie in the preconceived bias of how ecologists identify plant communities in the field. Statistical groupings often do not confirm the classification of plant communities as ecologists perceive them.

Dynamic Nature of Plant Communities

In addition to the question of continuum versus typal community, another area of philosophical debate is the meaningfulness of interpreting such factors as current community composition, trend, and productivity. Baseline data are supposed to reflect a predevelopment measure of the vegetational resource that may be affected by a given development. Often baseline data are collected for one or several years before a project begins. Ecologists are quick to point out that vegetational parameters vary from year to year. This variability has not, however, been well documented nor integrated into the law or experimental design.

An excellent example of the extreme year-to-year variability has been demonstrated in research conducted by Prodgers (1981) near Circle, Montana. He documented that tremendous variation in productivity, species composition, and range condition naturally occurs in prairie vegetation in response to climatic factors. The implications of Prodgers' four consecutive years of data (1977 through 1980) are significant, since the Soil Conservation Service's (SCS) methodology of determining condition classes and stocking rates is widely accepted and used by agencies with the responsibility to manage public lands. He stated:

> Classification of vegetation may not be suitable in another phase of the moisture cycle. Vegetation maps portraying actual vegetation may be subject to annual changes. Range condition estimates based upon species composition also may be subject to rather dramatic annual change, even in the absence of livestock grazing.

Prodgers' interpretations of the dynamic nature of plant communities are relevant to baseline data studies as envisioned and sanctioned by regulatory agencies. The distinct possibility that the spatial and areal characteristics of plant communities change annually in response to climatic factors calls into question management interpretations based on the assumptions that plant communities are relatively static commodities--that is, that gradual successional changes would not perceptively or substantially alter community composition from one year to the next.

Prodgers' data, collected for vegetation exclosed from grazing and dominated by climax species (*Agropyron smithii* and *Bouteloua gracilis*), showed that:

> The Bogr/Agsm exclosure (silty range site) rated a solid fair condition in 1977, even though grasshopper damage may have lowered the rating. In 1978 and 1979, the protected vegetation appeared to be in excellent condition with 90% of the theoretical climax community composition present. In 1980, a year of drought but few grasshoppers, the condition seemed to return to fair; about 30% of the theoretical climax was present.
>
> The Agsm/Bogr exclosure occupies a clayey range site. This exclosure rated a good (almost excellent) condition in 1977, 1978, and 1979, despite great variability in productivity values. However, in 1980, the condition slipped to poor, with less than 15% of the theoretical climax species present. Changes of this magnitude under exclosure conditions indicate a need to incorporate the effects of climatic fluctuations on both early and late successional vegetation into range condition estimates.

Correlation Between Plant Communities and Soil Types

The Montana guidelines for baseline studies require that correlations and explanations of relationships between plant communities and soil types be provided. The implicit assumption of this requirement is that there are definite, measurable, predictable, reciprocal relationships between soils and vegetation. Although many ecologists assert that there is a correlation between vegetation and soils, data are sparse which support this notion.

Weaver (1979) reported on the correlation of climax vegetation in Montana, with the 14 soil great groups. He found that in comparisons between the broad classifications of climax vegetation series and soil great groups that there was not an apparent 1:1 relationship. A 1:1 ratio might be expected because it is generally assumed that both soils and vegetation are determined to a large degree by climate and because they influence each other reciprocally.

Weaver believed the most likely explanations for lack of a 1:1 correlation between climax vegetation series and soil great groups were:

1) The soil may have developed under conditions different from those now existing at the site. This possibility has plausibility in that

Pleistocene and recent climates have varied considerably.

2) Soil qualities critical to plant performance (e.g., those affecting nutrient status, aeration, and water availability) may not be reflected at the great group level.

This is thought by Weaver to be plausible because texture, depth, and substrate characteristics become more important as the soil classification becomes more site-specific.

Although Weaver did not find the expected relationship between soils and vegetation at the broad level, a number of other studies have been conducted in Montana where plant community correlations with more refined soil units have been addressed (Culwell 1979, Quinnild et al. 1977, Olson-Elliott and Associates 1981b, VTN 1977, PKS 1981, Elliott 1981, Prodgers 1979).

In these studies, the precise methods used to derive the correlations between soils and vegetation are not described. I suspect, based on my experience in dealing with soils and vegetation data, that often correlations are determined by "eyeballing" the soils and vegetation maps. After the plant community map has been superimposed on the soils map, the more apparent areas of mutual overlap are noted. The resulting interpretation of the soils/vegetation correlation is based on a rather subjective or intuitive determination of which soil/vegetation units mutually occupy the same space. This method has drawbacks in that there is no measure of strength of correlation or adequate consideration where no correlation is apparent.

The only Fort Union Region study I know of that analyzed the correlation between soils and vegetation in a quantitative, non-subjective manner, was conducted by OEA (1981b). OEA conducted an in-depth, three-season, vegetation study near Birney, Montana, and produced a plant community map in addition to describing and measuring plant community parameters. A detailed soils map was prepared by another consultant after the SCS soils map of Rosebud County was deemed inapplicable because of its broad nature. The following description and data are from the OEA report.

> Transparent overlays of soils and vegetation maps were registered and secured to a base map (scale 1":400'). A dot grid was then placed over the maps and for each dot the soils type and vegetation type were recorded. . .
>
> The expected number of dots for each combination of soils and plant communities, assuming plant communities are randomly distributed among the various soils types, were calculated as follows:
>
> $$\hat{E}_{ij} = \frac{\sum_{j} n_{ij}}{N} \times \sum_{i} n_{ij}$$
>
> where $\hat{E}_{ij}$ = Expected number of dots that would occur in the i^{th} soil type and j^{th} plant community, assuming random distribution

$N = \sum_{i} \sum_{j} n_{ij}$ = Total number of dots counted

$\sum_{j} n_{ij}$ = Total number of dots counted in the ith soil type (summed over all plant communities)

$\sum_{i} n_{ij}$ = Total number of dots counted in the jth plant community (summed over all soils types)

The rationale for this formula is that if random distribution is assumed, then the probability of a dot falling in soils type "i" would be the area of that soils type (A_i) divided by the total area (A). Likewise, the probability of a dot randomly occurring in plant community "j" would be (Aj/A). The combined probability of a dot satisfying both conditions would be:

$$\text{Probability of dot in "i" and "j"} = P(i,j) \frac{A_i}{A} \times \frac{A_j}{A}$$

where $P(i,j)$ = Probability of dot in ith soil type and jth plant community

A_i = Area of ith soil type

A_j = Area of jth plant community

A = Total area being analyzed

Since area and dot counts are related by a constant factor ($A=fn$ or $A_i=fN_i$), then this probability, $P(i,j)$, can be expressed as:

$$P(i,j,) = \frac{A_i}{A} \times \frac{A_j}{A} = \frac{fN_i}{fN} \times \frac{fN_j}{fN} \times \frac{N_i}{N} \times \frac{N_j}{N}$$

where f = A constant factor that reflects dot counts and area

N_i = Dot count in ith soil type

N_j = Dot count in jth plant community

N = Dot count in total area

The expected number of dots falling in the i^{th} soils type and j^{th} plant community ($\hat{E}_{ij}$), assuming random distribution, would be the probability of occurrence, $P(i,j,)$, times the number of dots occurred, N, or:

$$\hat{E}_{ij} = P(i,j) \times N = \frac{N_i}{N} \times \frac{N_j}{N} \times N = \frac{N_i}{N} \times N_j$$

> where $\hat{E}_{ij}$ = Expected number of dots in i^{th} soils type and j^{th} plant community
>
> $N_i = \sum_j n_{ij}$ = Number of dots in i^{th} soils type, summed over all plant communities
>
> $N_j = \sum_i n_{ij}$ = Number of dots in j^{th} plant community, summed over all soils types
>
> The expected number of dots in certain combinations of soils and vegetation were calculated . . . The expected number of dots was not calculated for combinations with dot counts less than five due to low statistical significance.
>
> To facilitate comparison of dot counts and expected number of dots, the ratio of expected to actual was calculated and presented in Table F9-3 (OEA 1981b). Only values greater than one were tabulated since a value of unity would indicate that the number of dots counted was exactly what would be expected on a random basis. Any value less than one would indicate that a plant community occurs on a soil type less frequently than expected on a random basis. Conversely, the values tabulated (all greater than one) indicate that a plant community occurs on a soils type more frequently than expected on a random basis. The larger the value, the stronger the correlation or preference. The riparian plant community, for example, occurs on the Havre loam, Glendive sandy loam, and Lallie clay, 6.9, 33.5, and 3.6 times as often, respectively, as would be expected due to probability.

It can be seen from studying OEA's Table F9-3 that some plant communities and soils show definite correlations. It would be interesting to conduct the same objective vegetation/soils correlation on other sites. It may be that the Birney area studied by OEA represents an unusual site where the vegetation and soils are near climax and where the landforms are discrete and easily delineated. Other sites throughout the Fort Union Region might not be at appropriate stages of plant succession and as amenable to mapping as was the Birney site.

A study site at Cook Mountain near Ashland, Montana (Elliott 1981), approximately 20 miles north of Birney, differed considerably from the Birney site. At the Cook Mountain site, the topographic diversity created a mosaic of habitats which, due to differences in soils, moisture, and slope and aspect, supported a diversity of plant communities. The boundaries and species composition of the plant communities mapped were not always discrete. Many species comprising the communities occupied niches along environmental gradients. Thus, in some areas, a continuum of plant communities tended to exist.

TABLE F9-3. RATIO OF EXPECTED NUMBER OF DOTS TO ACTUAL DOTS COUNTED

	Plant Community												
Soil Type	Riparian	Marsh	PIPO/AGSP	JUSC/AGSP	Breaks	ARCA/AGSM	SAVE/AGSM	ARTR/AGSM	ARTR/Bunchgrass	Sidehill	AGSM/BOGR	ARDR/STCO	STCO/BOGR
Havre loam	6.9	--	--	--	--	<	<	--	--	--	<	--	--
Glendive loam	--	--	--	--	--	--	*	--	--	--	--	--	14.4
Harlem clay loam	*	--	--	--	--	4.4	*	--	--	--	1.3	--	--
Glendive sandy loam	33.5	--	--	--	--	--	1.4	--	--	--	--	--	*
Havre	*	*	--	--	--	5.8	3.3	--	--	--	2.7	--	--
Lallie clay	3.6	110.0	--	--	--	1.6	--	--	--	--	1.8	--	--
Busby sandy loam	--	--	--	--	--	*	--	*	--	--	--	--	*
Vanda variant clay	--	--	--	--	4.1	--	--	*	--	*	3.5	--	--
Busby sandy loam	--	--	<	--	--	*	--	<	<	<	<	7.2	2.9
Loburn sandy loam	--	--	*	--	--	--	17.0	*	1.7	*	--	--	--
Kirby very gravelly loam	--	--	<	--	--	--	--	<	2.3	1.6	<	3.2	2.3
Pinelli variant loam	--	--	<	--	--	<	*	1.3	2.2	<	1.2	3.5	2.2
Yamac sandy loam	--	--	<	--	*	1.4	*	<	<	<	3.9	<	<
Yamac clay loam	--	--	<	*	<	<	--	3.8	1.2	<	2.8	<	<
Kobar clay loam	--	--	<	--	<	<	--	2.7	2.3	<	1.7	<	1.2
Dollard loam Armells	--	--	*	--	<	--	*	1.8	3.2	<	<	*	2.3
Armells very gravelly sandy loam	--	--	*	--	--	*	--	--	--	5.9	*	--	--
Grobutte-Patent complex	--	--	<	*	<	<	<	<	<	4.3	<	<	2.4
Dollard variant-Blackhall complex	--	--	1.9	3.6	5.2	<	<	<	<	<	<	*	<
Yamac-Havre loams	--	--	<	--	1.6	--	<	5.1	<	<	1.8	--	<
Dollard-Blazon complex	--	--	<	--	<	*	*	1.4	3.8	<	<	1.1	*
Benz clay loam	*	--	--	--	--	*	23.9	--	--	--	--	--	*
Tisworth loam	--	*	--	--	<	*	21.6	--	*	--	<	--	--
Glendive-Glendive variant complex	--	--	*	--	--	11.9	<	<	*	<	<	--	<
Cooers-Rentsac variant loams complex	--	--	<	6.9	*	--	*	<	3.7	<	<	2.7	<
Kirby variant-Rentsac variant very gravelly sandy loams complex	--	--	3.5	*	<	<	*	<	<	2.6	<	<	<
Clinker rock outcrop-Talus association	--	--	1.8	--	*	<	*	*	*	5.0	*	--	<
Disturbed land	--	--	--	--	*	10.0	--	--	*	1.7	--	--	--
Birney sand loam	--	--	<	--	--	*	--	*	<	<	<	5.1	6.5
Sandstone rock outcrop	--	--	*	--	--	--	--	--	--	3.5	--	--	5.5
Wetlands	--	<	--	--	--	--	--	--	--	--	--	--	--

*Fewer than five dots counted.
<Plant community occurs on soil type fewer times than random expectations.

The distribution of dominant species, *Stipa comata*, *Agropyron spicatum*, *Bouteloua gracilis*, and *Artemisia cana*, was relatively unpredictable. The most enigmatic of distribution patterns was demonstrated by *Artemisia cana*. On many sites of the Fort Union Region, this species is restricted to drainageways or moist swales. At Cook Mountain, however, it was an important component of four upland community types as well as being a dominant species along drainageways.

The correlations of soils and vegetation at the Cook Mountain site was not particularly apparent when the soils and vegetation maps were superimposed on one another. The objective statistical methods of testing soil/vegetation correlations as presented by OEA (1981b) were not applied to this study, so the precise correlative dimensions were not ascertained. The reason that the soils and vegetation often did not show strong correlation could have been due to the fact that the soils studies were conducted as a broad mapping exercise over an entire county. The vegetation mapping units, on the other hand, were delineated at a highly detailed level.

In summary, it appears that a successful demonstration that soils and vegetation are correlated depends on the following factors:

1) The ease and accuracy with which plant communities and soils can be delineated and mapped at a given location.

2) The relative level of mapping detail or resolution for mapping both vegetation and soils.

3) The first factor is in turn dependent on such factors as the plant successional status of both soils[1] and vegetation, which is reflected in the visible measurable discreteness of the vegetation.

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[1] Weaver (1979) eliminated young soils (i.e., Inceptisols or Entisols) from his sample because they may not have been in equilibrium with either the climate or the vegetation.

VEGETATION CLASSIFICATION

Four of the most common vegetation classification systems used for baseline studies are: 1) range site, 2) habitat type, 3) existing community type, and 4) ecological response unit.

The range site system of classification is used by the Soil Conservation Service (SCS) in conservation planning. A range site is a basic soil/vegetation unit that is defined as: "A distinctive kind of rangeland that differs from other kinds of rangelands in its potential to produce native plants. A range site is the product of all environmental factors responsible for its development." The plant community found on a range site in the absence of abnormal disturbance and significant physical site deterioration is the climax plant community for that site.

The correlation between range sites and soils is assumed to be direct. Boundaries of range sites can be determined directly from soil maps.

The habitat type vegetation classification system is similar to the range site system in that both are based on the concept of potential or climax communities. A habitat type is a more or less discrete unit of vegetation that occurs in equilibrium with the various environmental factors of a given site. Combinations of soils, climate, and topography create environments that support characteristic and predictable associations of plants. The characteristic associations are relatively stable and are identified and mapped based on the presence and amounts of various indicator species.[2]

The habitat type system differs from the range site system in that there is no direct correlation between a given habitat type and a given soil unit. A habitat type appears to be more climate-determined than soils-determined.

The third common vegetation classification system focuses on the existing vegetation that comprises a given site. Classification of existing plant communities is based on the presence of two or more dominant species. (Dominant species are those which by structure, number, or coverage provide the functional characteristics of the type). In mapping existing plant communities, both seral and climax communities are attributed the status of separate vegetation types.

The fourth system, the ERU system, is based on combining existing vegetation with soils and landforms. Cook and Bonham (1977) describe an ERU as ". . . a more or less homogeneous unit that is similar in topographic features, soil texture, depth, and vegetation type." An ERU differs from other classification units in that slope, aspect, and landform are important descriptive features in addition to vegetation and soils.

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[2] Indicator species are those which, by virtue of their occurrence, indicate specific consistent environmental features such as slope, aspect, elevation and moisture availability.

Of the four classification systems, the most abstract are the range site and habitat type. Because both of these systems are based on potential vegetation, a given range site or habitat type may differ considerably in species composition between seral and climax stages. On the other hand, the conceptual framework for classifying existing vegetation is quite straightforward because it is relatively simple to visually discern the dominant species.

Threatened and Endangered Plant Species

The Endangered Species Act of 1973 was established to provide statutory protection at the Federal level for threatened and endangered plants and animals. The States vary in regard to the statutory and policy guidelines concerning threatened and endangered plants.

Most States require that endangered or threatened plants and habitats be inventoried as part of baseline vegetation studies associated with coal mines. Often, however, baseline studies are not conducted in sufficient intensity to locate and identify those species which may be rare or endangered. The cost of conducting an adequate search for endangered or threatened plants can add considerably to the cost of the baseline study.

In general, the study and management of endangered or threatened plants of the Fort Union Region have been superficial. An intense baseline study of a relatively small area proposed for mining may reveal, for example, the presence of a species thought to be threatened or endangered. Because, however, the surrounding area outside of the proposed mine study area may not have been adequately studied, the status of the species cannot be accurately assessed.

By conducting intense baseline studies over limited and sometimes isolated areas of the vast Fort Union Region, it could be expected that the number of plants suspected of being threatened or endangered would increase. It has been suggested by the more cynical that the number of threatened or endangered species correlates directly with the number of botanists who look for them.

Until the Fort Union Region has been studied at a uniform level of intensity, the status of endangered or threatened plants will remain obscure. The means whereby the necessary funding can be obtained for a uniform study of the Fort Union Region, however, remains even more obscure.

Species Diversity

The concept of characterizing plant communities on the basis of species diversity has been addressed by numerous plant ecologists (Bonham 1974, McIntosh 1967). Indices have been developed which provide a numerical measure of species diversity for stands and communities.

In addition to being a descriptive feature of plant communities, species diversity is also interpreted by ecologists in terms of habitat quality. It is generally believed that plant communities with high species diversity provide superior wildlife habitat and are ecologically more stable or resilient to environmental perturbations.

State and Federal regulatory and management agencies recognize that species diversity is an important attribute of plant communities and require that pre- and post-mining studies include measures of species diversity. A goal in reclamation is to establish plant communities comparable to native plant communities in species diversity.

An ecological attribute of high species diversity is demonstrated by biomass production in native prairie vegetation. Native prairie vegetation is composed of plant species which maximize the growth potential of a given site by efficiently exploiting available moisture and adapting physiologically to intense solar radiation, high leaf temperatures, and periodic water stress.

A native prairie plant community is typically composed of cool season and warm season grasses, forbs, and annuals. Cool season grasses are morphologically, physiologically, and anatomically adapted to attaining their maximum growth in spring and early summer. Warm season grasses are similarly adapted to producing their greatest growth from mid to late summer. Annuals avoid mid and late-season moisture stress by rapidly completing their life cycle (seed germination through seed production) during the most favorable period of the growing season. Perennial forbs, which are present in prairie vegetation throughout the growing season, store photosynthetically produced carbohydrates in underground roots, tubers, and rhizomes.

The significance of the seasonal synchrony of production in native vegetation is that growth continues throughout the growing season. Thus, there is no single time during the growing season when it is possible to accurately sample the total production of the community.

On reclaimed lands, in comparison, the dominant growth is commonly provided by cool season grass species, such as Agropyron spp. Production sampling in late July, for example, at the end of the major growth period, would usually reflect relatively accurate seasonal biomass production. If production measurements of reclaimed vegetation, based on a single sampling period, are compared with production measures similarly collected for native vegetation, invariably the production of native vegetation is underestimated.

To accurately measure seasonal biomass production of native prairie vegetation, samples would have to be taken several times during the summer. It would also be necessary to measure the carbohydrate reserves stored in underground plant organs.

The synchrony of biomass production throughout the growing season is directly related to species diversity. The more diverse a community is in species, the more likely the community will be to maximize the season-long growth potential of a site and produce a sustained level of food and cover for wildlife and livestock.

VEGETATION AND WILDLIFE

Studies in Montana

An important management application of baseline vegetation data relates to wildlife habitat studies. Wildlife habitat classification systems are closely linked with vegetation. Generally, wildlife habitat categories are determined on the basis of the dominance of plant species that provide structural qualities to habitat. For example, a plant ecologist might identify three silver sagebrush communities based on the understory species of dominance, whereas a wildlife biologist tends to include the various silver sagebrush communities as a single habitat unit--silver sagebrush/grassland.

OEA (1981b) classified wildlife habitat near Birney, Montana, where an extensive vegetation inventory was also conducted (OEA, 1981a). Based on these studies, the relationship between wildlife habitat and plant communities is depicted in Table 1.

The value of a given habitat unit for wildlife depends on features such as:

1) The amount of food/forage available during a given season or seasons.

2) The cover/escape value, which is dependent on factors such as topography, density of vegetation, and height of vegetation.

3) The overall species and structural diversity of the study area under consideration.

4) The level of unnatural intrusions on wildlife during sensitive periods of the year.

TABLE 1. CORRELATION BETWEEN PLANT COMMUNITIES AND WILDLIFE HABITAT

Plant Community	Wildlife Habitat
Western wheatgrass/blue grama	Perennial grassland
Big sagebrush/western wheatgrass	Big sagebrush/grassland
Silver sagebrush/western wheatgrass	Silver sagebrush/grassland
Greasewood/western wheatgrass	Halophytic shrubland
Big sagebrush/Bunchgrass	Big sagebrush/grassland
Needle-and-thread/blue grama	Perennial grassland
False tarragon/needle-and-thread	Perennial grassland
Sidehill complex	Bunchgrass
Ponderosa pine/Bluebunch wheatgrass	Ponderosa pine/juniper
Breaks complex	Breaks
Rocky Mountain juniper/Bluebunch wheatgrass	Juniper
Idaho fescue/Bluebunch wheatgrass	Bunchgrass
Wooded riparian	Deciduous stream bank/upland seep

The U.S. Fish and Wildlife Service (1980) devised the Habitat Evaluation Procedure for rating habitat units on a scale of 1 to 10 (1 = poor, 4 = fair, 7 = good, and 10 = excellent). Examples of how mule deer and sharp-tailed grouse habitats were rated is shown in Table 2.

The Habitat Evaluation Procedure is a means whereby habitat can be evaluated without actually observing the presence of wildlife. Many studies, however, depend on observations throughout the year to evaluate habitat use and preference. Direct observations of wildlife determine which habitats serve as feeding areas and which habitats provide cover for resting or escape on a diurnal and seasonal basis.

Thompson (1978) studied wildlife habitat use in McCone County and found that the following habitats were the most important for wildlife:

Riparian (includes floodplain cottonwoods and upland box elder and green ash coulees).--This was the most structurally diverse of all habitats studied and supported the greatest faunal diversity. This habitat was found to support more species of breeding or wintering birds than any other habitat. Foliage height diversity and vertical layering of vegetation provided the high habitat quality. Whitetailed deer and ring-necked pheasants attained the greatest density in this habitat.

Tall Coulee Shrubbery.--Deeply-eroded coulees supporting tall shrubs such as silver buffaloberry, red-osier dogwood, and chokecherry were extremely important to mule deer, sharp-tailed grouse, songbirds, and small mammals. In the treeless expanses of eastern Montana, these coulees provide the only cover for many large and medium-sized birds and mammals, and the only nesting habitat for shrub-nesting birds.

Silver Sagebrush.--Stands of silver sagebrush with greater than 25 percent coverage were found to be of high importance to sharp-tailed grouse, white-tailed jackrabbits, sage grouse, wintering pronghorn antelope, breeding birds, and small mammals.

Near Birney in Rosebud County, OEA (1981a) found the following habitats to be the most important to wildlife.

Ponderosa Pine/Juniper.--This habitat was heavily used by mule deer and sharp-tailed grouse throughout the winter. Isolated stands of pine/juniper are used for wildlife security, feeding, roosting, travel corridors, and nesting/brooding sites.

Deciduous Streambank.--The riparian forest along the Tongue River provided important habitat throughout the year for white-tailed deer, ring-necked pheasant, and raccoon. Many species of songbirds and some raptors, including great horned owls and red-tailed hawks, nested in the deciduous shrubs and trees.

Silver Sagebrush/Grassland.--This habitat was heavily used by mule deer, white-tailed deer, and sharp-tailed grouse in the fall, and ring-necked pheasants in the summer. Due to the higher moisture levels in this habitat, it is probable the vegetation remains succulent late into the fall, thereby increasing its attractiveness to wildlife species.

TABLE 2. HABITAT EVALUATION OF PONDEROSA PINE/JUNIPER FOR MULE DEER AND SHARP-TAILED GROUSE

Sharp-tailed Grouse

Rating*	Criteria
10	North slopes with 10 to 12 inches of effective residual grass cover for nesting. Shrub crown cover of 30 to 45 percent in coulees. Shrub coulees with serviceberry, chokecherry, snowberry, wildrose, and buffaloberry. Shrubs having all terminal leaders alive (professional judgment). Grasses and forbs abundant and in good condition between forest area (professional judgment).
7	North slopes with 8 to 10 inches effective residual grass cover. Shrub crown over 45 to 60 percent in coulees. Same shrub species. Shrubs with 75 percent of terminal leaders alive. More grasses and less forbs between forest areas.
4	North slopes have effective residual grass cover of 6 to 8 inches high. Shrubs in coulees with 20 to 30 percent crown cover. Some deciduous species present but mostly juniper. Deciduous shrubs somewhat decadent (50 percent of terminal leaders alive). Understory sparsely vegetated.
1	Residual grass cover less than 6 inches tall. Only juniper present and in good condition. Grading into sage/grassland.
	Mule Deer
10	Interspersion of ponderosa pine with patches of sage/grassland on smaller ridgetops, and along margins of more extensive ridges with sage abundant in these areas for winter use. Forbs (especially yellow sweet clover) and skunkbush available in summer and fall. Other shrubs as snowberry, rose, and chokecherry also available in summer and fall. Shrubs, including big sage and rubber rabbitbrush, available in winter in good condition with no hedging.
7	Interspersion of pondersoa pine with patches of sage/grassland along major ridgetops and sage abundant. Yellow sweet clover available in summer. Skunkbush very sparse. Big sage and rubber rabbitbrush available in winter in fair condition with some hedging.

Table 2 (continued)

Rating*	Criteria
4	Interspersion of ponderosa pine with some patches of sage/grassland along major ridgetops and sage scattered. Yellow sweet clover very scarce as is skunkbush summer and fall use. Big sage available in winter in poor condition with moderate hedging.
1	Ponderosa pine on moderate slopes with no sage/grassland interspersed. Few palatable forbs or shrubs as above. Those present are in very poor condition and heavily hedged.

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*1 = poor, 4 = fair, 7 = good, and 10 = excellent

Overview

In reviewing both baseline vegetation and wildlife studies, it becomes apparent that data collected during vegetation inventories are sparingly used by wildlife biologists. It appears that wildlife biologists require vegetation information that is not usually collected during baseline studies. Ecological interpretations of wildlife ecology are heavily dependent on data pertinent to seasonal food availability and on the structural characteristics of habitats. Measurements of the diversity of the grass/forb litter, the litter layer, the shrub layer, and the tree overstory at various heights in the canopy are important in interpreting habitat use and preference by wildlife species. Data on production of key browse or forage species would be useful in interpreting the use and preference of habitats by various wildlife species.

Typically, baseline studies measure aerial biomass of perennial grasses, annual grasses, forbs, and shrubs. There is usually no attempt to segregate species of high value to wildlife. Also, the timing of baseline measurements usually coincides with the peak of biomass production in mid-summer. Mid-summer is usually not a time of stress to wildlife because food, water, and cover are at their peak in terms of quality and abundance. Measurements of vegetation parameters in the spring and fall would be more useful in interpreting habitat preference. For example, measurements of phenology and production of grasses and forbs in the spring and measurements of leader length of browse species, fruit production of shrubs, and green-up of grasses and forbs in the fall would provide useful wildlife information.

In summary, it appears that if baseline vegetation studies are to provide optimal levels of information for wildlife biologists, experimental design changes must take place. Emphasis must be placed on vegetation parameters that have significance to wildlife ecology. Currently, Montana law does not reflect a philosophy that closely integrates the collection of baseline vegetation data with wildlife baseline studies.

CONCLUSION

After reviewing published literature and unpublished data on baseline vegetation studies, it is apparent that a tremendous body of information has been gathered. Most of the data are not, however, easily obtained or reviewed by the public or the scientific community. The fact that this great body of technical information is rarely published or subjected to peer review is disturbing. Because most baseline data remain obscurely filed in the archives of regulatory agencies, they remain relatively unused, and there is rarely a critical review of methods or interpretations other than to determine whether they conform to bureaucratic standards.

It is essential in the current era of tight money and disenchantment with environmental laws to be able to design studies which maximize the efficiency of data collection. Anyone who sets out to conduct a baseline study should try to eliminate unnecessary data acquisition.

The cost of energy and natural resource development continues to increase. Baseline data collection and other environmental work are included in the cost of products to the consumer. Unless the time and money spent on baseline data collection can be justified and data can be used in planning and management, consumer disfavor may create a backlash against spending money on this type of work.

As a strong proponent of protecting environmental integrity, I sincerely hope studies which contribute to wise and sustained use of resources are not just transitory phenomena. All resource managers must accept the responsibility for insuring that data collection is closely coordinated with actual data use and needs. Superfluous measurements of ecological parameters will fill files but will do little to sustain the rich.

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THE IMPORTANCE OF RIPARIAN VEGETATION COMMUNITIES IN COLORADO, MONTANA, WYOMING AND NORTH DAKOTA

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INTRODUCTION

The objective of this review is to acquaint land managers with the characteristics of riparian ecosystems and to explain why the management of these systems is crucial to man, livestock, and wildlife. Specific riparian habitats from the States of Colorado, Montana, Wyoming, and North Dakota, will be described and current policy statements from agencies in charge of riparian management will be included. Finally, mitigation possibilities will be examined and management procedures for tempering some of the more destructive uses of riparian ecosystems will be addressed.

Description and Importance

In the past, authors have avoided strictly defining riparian ecosystems but have relied upon the descriptive approach instead. Hirsch and Segelquist (1978) generalized by stating that riparian systems are characterized by streamside or riverside vegetation with more mesic and hydric growth habits than adjacent upland communities. Odum (1978) stated that riparian zones are well-defined landscape features that have many of the same values and land use problems as wetlands in general. Western riparian areas can be regarded as stream-wide brushy plant communities (Almand and Krohn 1978) or flood-plain communities where the vegetation is dependent on overbank flooding for the deposition of substrates and nutrients necessary for regeneration, establishment, and maintenance (Hirsch and Segelquist 1978). Riparian systems vary in size and vegetative complexity because of the many combinations of ecological parameters that can be created between water sources and physical characteristics of a site (Thomas et al. 1979). Odum (1971) described such site physical attributes as gradient, aspect, topography, soil, type of stream bottom, water quality, elevation, and plant community.

While it is apparent that a single statement cannot characterize riparian communities, riparian zones in general within the semiarid Western United States contain the following qualities: (1) they create well-defined habitats within a predominantly semiarid zone, (2) the total area occupied is relatively small, (3) production of plant and animal biomass is greater than in surrounding areas, and (4) they are a critical source of floral and faunal diversity (Carothers et al. 1974).

Riparian habitats are ecotonal between aquatic and terrestrial habitats (Odum 1978) and exhibit high edge-to-area ratios. This high ratio provides water, cover, food, and space to terrestrial wildlife. In addition, many smaller species are restricted or endemic to the riparian habitat. The riparian waterway also provides relatively safe transportation as animals move from one location to another (Fig. 1).

The riparian habitat often extends its influence beyond the immediate riparian vegetative community. Carothers (1977) conducted studies in both river valley and mountain riparian types and demonstrated that population densities of

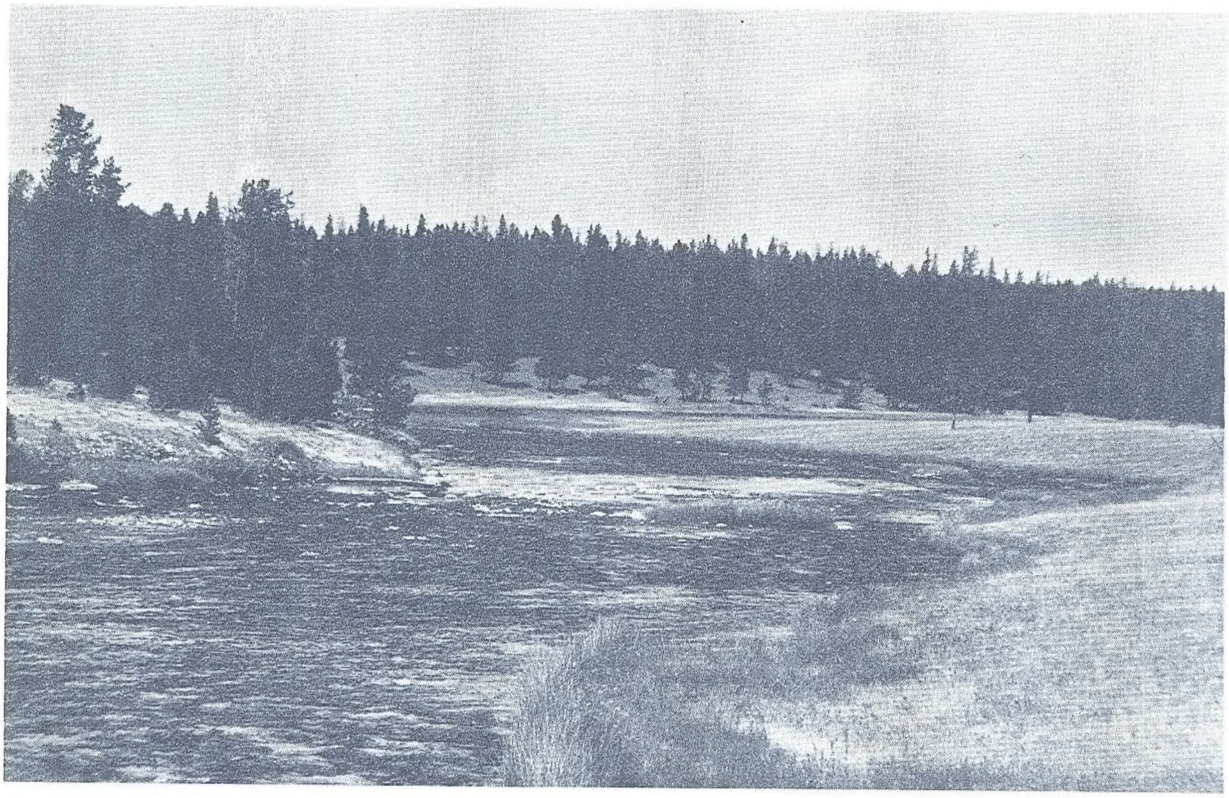


Figure 1. Riparian areas provide lush forage and waterway transportation.

birds in habitats adjacent to the riparian type are influenced by the presence of a riparian area. This influence may extend to several hundred meters beyond the streambank. Therefore, if riparian habitat is severely disturbed, the effects will extend to adjacent areas.

Vegetation bordering the channel supplies and retains organic matter on site, thus sustaining the productivity of aquatic communities. Streambank herbaceous and woody material provides shade that limits plant growth within the channel and contributes large quantities of organic matter to the stream as leaves and twigs. This type of plant material comprises up to 90 percent of the detrital organic matter necessary to support headwater stream communities (Cummins and Spengler 1978). Another source of organic matter is aquatic plants. In addition, stream and river channel and flood-plain obstructions--i.e., branches, logs, and rocks--retain concentrations of organic matter and confine the nutrient supplies to the immediate area.

Riparian ecosystems provide silt, which, when laid down by floodwaters, forms rich soils for growing timber in bottom lands. In addition, these areas produce large amounts of forage for livestock. High-quality streams with gravelly beds support fish populations. Road construction is usually less expensive near riparian zones because of flatter topography. Mining activities that use large amounts of water are often located near riparian systems. Recreationists concentrate in these areas (Nash 1977). This variety of demands for use of riparian systems can create conflicts. As a result, these areas require site-specific management to assure the perpetuation of this valuable resource. Historically, man has recognized the importance of riparian systems but has tended to abuse them.

Historical Considerations

Man's survival and progress have depended heavily upon riparian vegetation, soils, and wildlife. American Indians first settled river valleys and used water for themselves, their livestock, and for agricultural production. Settlers and early fur trappers of the Northern Great Plains and Rocky Mountain States relied on rivers and streams not only for navigation but also

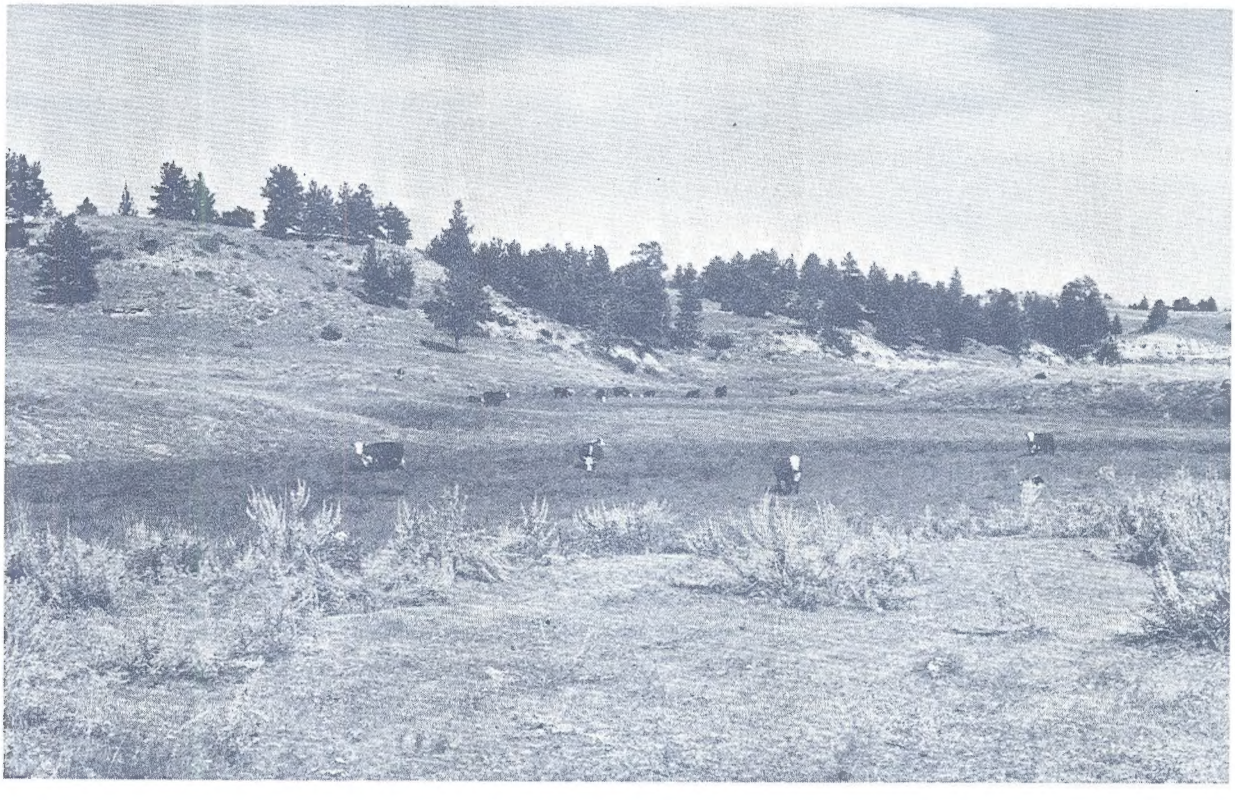


Figure 2. Cattle congregating on subirrigated riparian sites.

for richness of soils and game. Burlingame (1980) documented the exploits of Montana and North Dakota explorers, and how the rivers and streams provided beaver for fur hats, and cottonwood trees for dugout canoes and rafts. Ohmart et al. (1977) examined the riparian history of the Colorado River and concluded that due to man's activities, cottonwood communities have declined substantially along the river and with them certain avian species have declined. Encroachment on riparian systems continues to the present. The pressure to put some riparian habitat to other uses is strong. Fox (1977) stated that economic pressures, in conflict with environmental concerns, pose an inevitable threat to vegetation and wildlife. Since these pressures are real, land managers must keep in perspective the fragility of these systems and their sensitivity to disturbance.

Riparian zones occupy relatively small areas of the Western United States and should be considered vulnerable to disturbance. The character and stability of these zones are influenced by topography, vegetation, soil type, climate, and man's activities (U.S. Fish and Wildlife Service 1980). More mature vegetation is apt to assume distinct boundaries and strata that intensify edge effect and increase diversity. This maturity implies that the area is sensitive to management activities within the riparian zone itself or on the surrounding rangeland. Avifauna will provide vertical diversity within these strata via territorial occupation. When man's use of these riparian areas becomes too intense, a chain of events begins that ultimately lowers stream quality and decreases the ability of the area to support plant and animal life.

STREAM AND RIVER DYNAMICS AND ECOLOGICAL STRUCTURE AND FUNCTION

Before describing specific habitats, I will briefly explain the dynamics and ecology of rivers and streams. Riparian systems, unlike lakes, marshes, and bogs, are flowing water systems. The land manager must understand stream behavior if he is to anticipate the results of his management decisions with regard to riparian systems. For example, a management technique that alters vegetative cover on a watershed can increase water yield (Campbell 1970, Hibbert 1971), or streamside forest removal can activate bedload transport (Heede 1977). Streams are dynamic ecosystems (Heede 1975), much like terrestrial ecosystems. Nutrient flow and energy cycles typify both systems. Change in the hydrologic system may bring about adjustment if a geomorphic threshold is exceeded. Terrestrialaquatic interactions are complex, and the manager, mining engineer, and reclamation specialist should be aware of the consequences of their decisions.

Fluvial Processes

Stream Characteristics

Even to the casual observer it is obvious that streams and rivers are dynamic. What is usually a meandering stream, not filling its streambed, can become an uncontrollable, high-flow system during spring runoff in the Western United

States. The tranquil flow is termed subcritical and exerts low energies on banks and beds (Heede 1980). High, rapid water flow in Western rivers and streams, such as during snowmelt, is termed supercritical flow (Fig. 3). Energy expended on streambanks during supercritical flow may alter unprotected channels. Not all flow stages are caused by nature; human activities, such as building diversion structures or bank revetments, can have detrimental effects on channel geometry, such as narrowing the channel to cause supercritical flow. Alluvial rivers and streams are continually changing position and shape as a consequence of hydraulic forces generated by sub- or supercritical flow upon their streambanks.

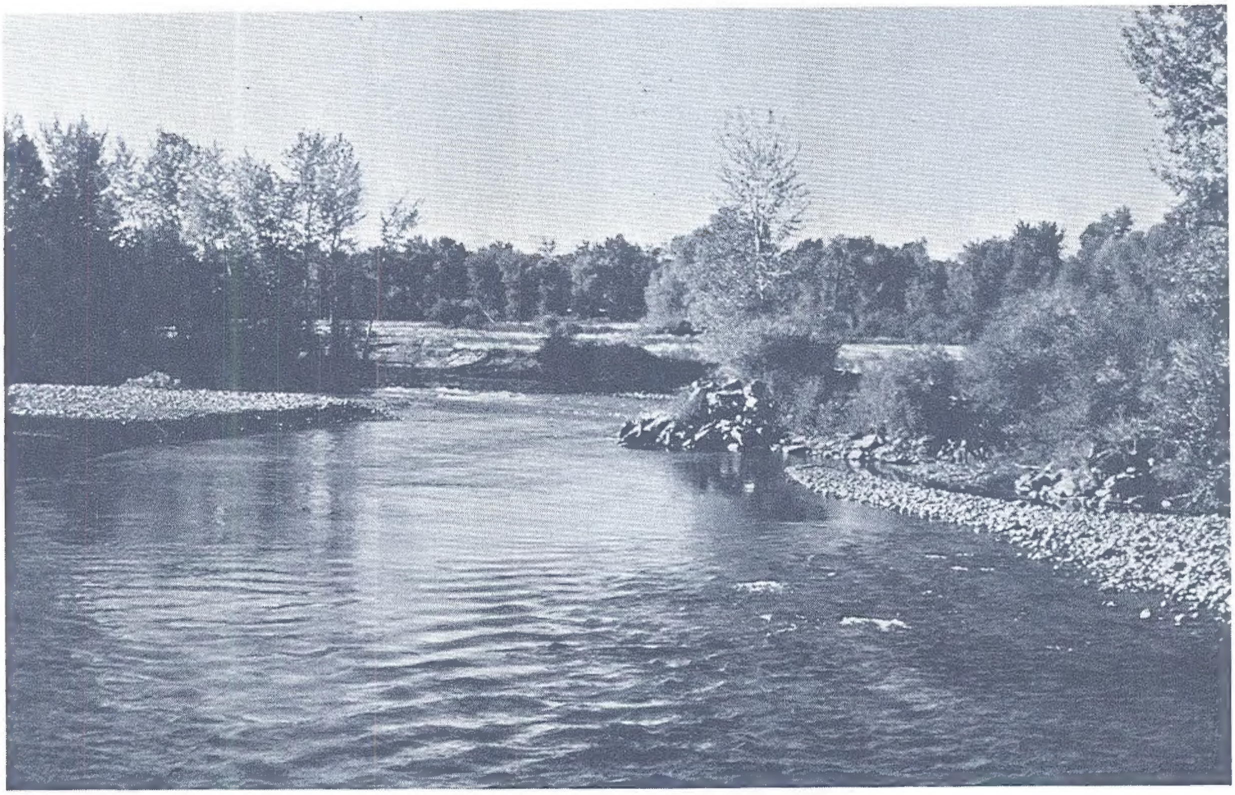


Figure 3. Meandering rivers such as the West Gallatin in Montana may turn into supercritical-flow rivers during spring runoff.

It is not the purpose of this paper to dwell on the hydraulic processes affecting water discharge and sediment load, but the following six facts are presented as a summary of research results by Land (1955) and Schumm (1971) on rivers and streams not altered by man: (1) depth is directly proportional to discharge and inversely proportional to the bed-material discharge; (2) channel width is directly proportional to discharge and sediment load; (3) channel shape (width-depth ratio) is directly related to sediment load; (4) meander wavelength is directly proportional to discharge and to sediment load; (5) gradient is inversely proportional to discharge and directly proportional to sediment load and grain size; and (6) sinuosity is proportional to valley slope and inversely proportional to sediment load.

It is hoped that these relationships will help to determine the rsponse of nearly all water-conveying channels. As these independent variables change, major adjustments of channel morphology can be predicted. In addition, if man-induced changes in sinuosity and meander wavelength as well as in width and depth are required to compensate for a hydrologic change, a long period of channel instability can be anticipated, with bank erosion and lateral shifting of the channel prior to restoration of streambank stability (Simons 1975).

Channel Form and Shape

Variables affecting alluvial river and stream channels are numerous. Because they are interrelated, it is improbable that one may isolate the role of an individual variable. Any changes imposed on a river will affect form. Broad classifications of river form are braided, straight, or meandering, or some combination of these classes (Simons 1975). River forms are highly dependent on valley longitudinal slope. By changing the slope it is possible to change the river from a meandering one (subcritical flow) to a braided one that varies rapidly with time, has high velocity and carries large amounts of sediment. The opposite effect on form can be obtained by slightly decreasing the slope. Other factors affecting stream channel forms are (1) stream discharge; (2) sediment load; (3) bank and bed resistance to flow; (4) streambank vegetation; (5) geology, including type of sediments; (6) seepage forces; and (7) human influences.

Managers should be primarily interested in channel shpae, because of the influence of (1) quantity of water; (2) the type of sediment load (suspended load is the material moving in suspension, while bedload is the coarser material moving on or near the bed); and (3) the type of bank material. As with all hydrologic processes, a change in one of these attributes causes change in the others which will alter channel shape. Causes of shape change are not easy to identify because of turbidity of the water or presence of transitional shape changes caused by constant hydraulic activity. Identification of a particular shape or force requires much study and observation over time.

Management practices can influence water and sediment discharge. Stream training measures such as riprap change banks and alter their material makeup. These changes may benefit or be a detriment to management goals. A semicular cross section would convey the largest amount of water with the least resistance. The more channels deviate from this ideal shape, the less water is conveyed, and the higher the resistance to flow. A wide, flat channel would therefore show tendencies for aggradation by sediment.

Soil particle size distribution in the streambanks also influences flow resistance and determines channel shape. While banks with a high silt-clay content lead to narrow and deep channels, those with a predominance of sand and coarser material develop into wide, flat channels (Heede 1980). Consequently, lateral stream movements may lead to shape changes by exposing different soil textures within the banks. These particle size principles in the streambank may also be carried over into sediment particle size. Relationships between shape and sediment load show channel width increases with increasing coarseness of sediment particle size.

Channel Particulates

Land (1955) found a direct proportional relationship between sediment discharge (affected by sediment particle size) and water discharge (influenced by slope) for stable channels. In effect, alterations of sediment or water discharge require changes in particulate grain size and/or slope. Hence the equilibrium between the proportionality is maintained. For example, if the slope is increased the stream will attempt to transport larger particles (if available), or if stream discharge decreases, sediment load must also decrease to maintain the established equilibrium (Heede 1980). Alteration of these channel characteristics may influence biological habitats.

Land-water interactions relating to erosion are a primary concern to land managers. Erosion problems can be the most catastrophic land-water interaction affecting downstream riparian ecosystems. A major function of riparian vegetation is to act as a filter against sediment and debris which would otherwise be carried into the stream. The undisturbed herbaceous communities within the riparian zone are effective in reducing the impacts of this runoff. Interference with the biotic regulation of streambank and overland erosion could result in physical and biological changes in riparian watersheds. Bormann et al. (1974) stated that removal of biotic regulators, such as vegetational cover, within the overland terrestrial system may lead to significant soil and underlying mineral erosion. Ecosystem microhabitats are changed (Likens and Bormann 1972), habitats are physically disrupted, turbidity may restrict the penetration of solar radiation,, and water chemistry relations may be altered (Likens and Bormann 1974). Another significant erosion problem is that related to perpetuation of fish populations, especially salmonids.

Sediment which affects salmonids (various Pacific salmon, trout, and char) occurs in two general forms. First, suspended sediment can be harmful if concentrations are high and persistent (Cordone and Kelley 1961). Under these conditions, silt may accumulate on the gill filaments and impair the ability of the gills to aerate the blood; death by anoxemia and carbon dioxide retention occurs (Meehan et al. 1977). Second, excessive bedload sediment reduces the flow of intragravel water, which limits the supply of oxygen available to incubating eggs and alevins (Vaus 1962, McNeil 1966). Bedload sediment may also act as a physical barrier to newly hatched fry emerging from the gravel.

Stream Ecology, Structure and Function

Freshwater ecosystems occupy a relatively small portion of the earth's surface but are of primary importance to man because: 1) they are the most convenient and cheapest courses of domestic and industrial water, 2) they are a limiting factor in the hydrologic cycle, and 3) they provide a cheap and convenient avenue of waste disposal. Odum (1971) classified freshwater habitats as either standing water (lentic) or running water (lotic). As previously stated, riparian habitats are within the lotic classification. Stream and river ecosystems exhibit the same ecological attributes as terrestrial ecosystems. For example, there are both temporal and spatial changes. Stream ecosystems undergo both autogenic and allogenic succession. There is a complex detrital system in the stream to which riparian vegetation contributes directly. It is in the interest of the land manager and the reclamation specialist to be aware of the basic ecology of these systems before water becomes man's limiting factor.

Spatial Zonation

While zonation due to age or species presence may be horizontal in a lake or pond, in streams or rivers it is longitudinal. In streams or rivers we may find increasingly older geologic stages from the headwaters (source) to the mouth. Changes in community composition are more pronounced in the upper part of streams because the gradient, volume of flow, and chemical composition of the water changes more rapidly there. Shelford (1911) studied succession of fish communities in streams where the gradient of flow was not too different from the source to the mouth. Species found near the headwaters were generally tolerant of changing conditions and were found throughout the length of the stream. Other species occupied various sections of the stream. Thompson and Hunt (1930) found that while fish size increased but number of individuals decreased downstream, biomass density remained approximately the same. Burton and Odum (1945) found fish species differences were due to variations in temperature, current velocity, and pH. Low temperatures and high-velocity currents at the headwaters meant limited fish species. Selected populations reappeared at discontinuous intervals farther downstream. This trend in species variation appears to change with the various functional groups occupying the system.

Rivers and streams are classified into stream orders based on the number of tributaries of the main stem. As such, different aquatic functional groups occupy a particular habitat in the river based on stream order. As the stream order increases there is a decrease in influence of the adjacent terrestrial vegetation of the watershed and an increase in importance of upstream tributaries. With regard to within-stream production, the midregion (stream order 4 to 6) is seen as the major zone of plant growth, where the ratio of gross primary production (P) to community respiration (R) is greater than 1 ($P/R>1$). Lesser and greater stream orders are generally characterized by $P/R<1$. What is seen at the midregion is a shift from heterotrophy or autotrophy (see following explanation).

Stream Structure and Function

Riparian vegetation is essential to the biota of small streams and rivers. The vegetation is the system's source of energy and organic matter (Fisher and Likens 1973). Cummins (1974) and Merritt and Lawson (1978) stated that the utilization of a majority of this organic input occurs during fall and winter--the period of lowest temperature. Stream systems are highly dependent on riparian vegetation as their food source (heterotrophic) and contain organisms which can process organic matter at relatively low temperatures.

A portion of the reduced carbon compounds entering the stream as particles (particulate organic matter or POM) and in solution (dissolved organic matter or DOM) and material produced in the stream itself are processed to carbon dioxide and nutrients (Cummins 1974). The mean annual decomposition coefficient ws 0.3 for northern wetlands (Brinson 1977). Certain amounts are bound up in current biomass and the rest is transported downstream. Brinson (1977) reviewed the literature and found that rivers with streamside riparian vegetation carried more DOM than those without riverine wetlands. This could be important in downstream management of fish populations and in encouraging mitigation practices on fragile riparian ecosystems.

After the introduction of coarse particulate organic matter (CPOM) such as leaves, conifer needles, twigs, fruits, seed, flowers, etc., two processes rapidly occur (Fig. 4). First, soluble organic matter leached from the CPOM enters the DOM pool (Cummins 1974). The majority of this leaching occurs within 24 hours of initial wetting. The amount of DOM produced is dependent upon the degree of degradation of riparian CPOM. The second process is colonization of CPOM surfaces by cells and spores of bacteria, spores of aquatic hyphomycete fungi, and protozoans (Cummins 1974). This colonization is nearly complete within 2 weeks and the rate is primarily dependent on the preconditioning of the riparian substrate. Fine particulate organic matter (FPOM) is formed via these processes.

A number of functional groups are involved in the stream litter decomposition process. Location of these groups is influenced by stream order. A group known as shredders, which are found predominantly near the headwaters and feed on CPOM, include certain species of caddisflies and craneflies. Filtering FPOM from these first- and second-order streams are netspinning caddisflies, blackfiles, and certain midge species. This functional group is known as a whole as collectors. As the stream order increases, shredders become less important and collectors proportionately more important. By the fifth order,

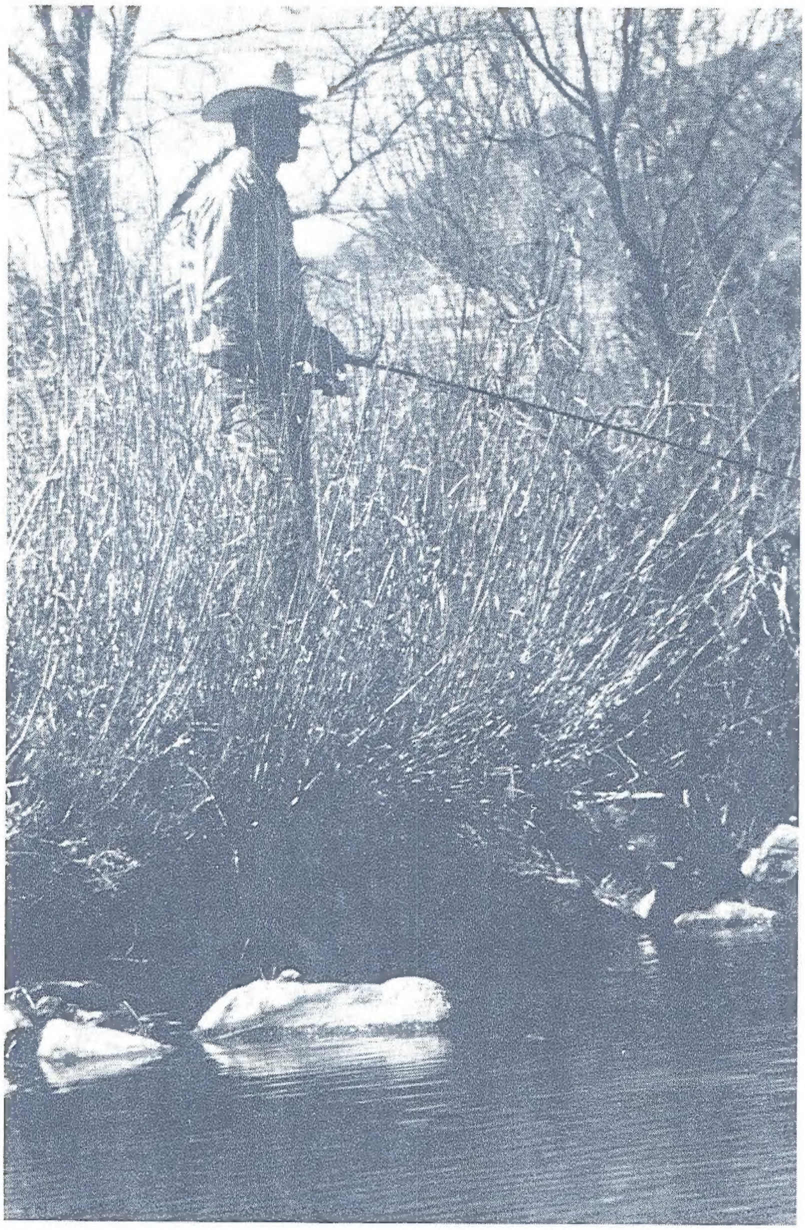


Figure 4. Overhanging streambank vegetation contributes coarse particulate organic matter (CPOM) to the detrital food chain.

grazers (along with collectors) become codominant invertebrate functional groups. Species of caddisflies, mayflies, snails, and beetles comprise the grazer functional group. As the stream order becomes greater than eight, only collectors are regarded as an important functional group. Predators are a minor portion within each stream order, and these include helgramites, dragonfiles, tanypod midges and several species of stoneflies. Fish are also predators and are found in all stream orders. These species are also influenced by stream order chiefly because of the food source. Invertebrate eaters reside in the headwaters area, fish and benthic invertebrate eaters are found in the midregion (stream order 4 to 6), while plankton feeders are found primarily in the larger rivers (Cummins 1973).

It is important to briefly discuss the major macroinvertebrate groups which process litter in the flood plain. The flood plain is a depositional region with regard to the accumulation and temporary storage of organic debris resulting from litter fall. Merritt and Lawson (1978) pointed out that events occurring in the riparian area determine the quantity and quality of organic materials (primary CPOM) that streams receive. They noted that in Western coniferous forests, the organic material entering the stream from the bank was 1.5 times greater than that of litter fall. This demonstrates the importance of the riparian flood plain as a temporary storage and potential preprocessing area for detritus such as leaf ltter.

Generally, the major macroinvertebrate groups involved in decomposition of leaf litter on riparian flood plains were Oligochaeta, Diptera, Grastropoda, Diplopoda, and Isopoda (Merritt and Lawson 1978). The peak activity periods were in the spring and fall, but the major season for leaf litter processing was in the spring. Peterson and Cummins (1974) have shown that newly fallen leaves are not fed on by macroinvertebrates for many weeks after leaf fall although they are soon invaded by microorganisms, primarily fungi. As was stated earlier, the primary processing time for stream litter is during the colder seasons of the year. Major stream macrofauna include Trichoptera, Plecoptera, and Diptera (Merritt and Lawson 1978).

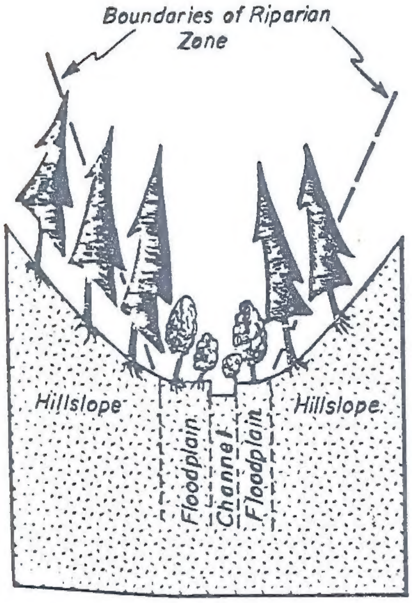
It can now be seen that an organic flow has begun with processing of litter on the riparian flood plain or streambank in the spring and a decomposition continuum into the winter in the stream itself. The litter is acted on by specialized micro- and macrofauna at each juncture. As the litter is processed through stream orders, different functional groups become processors. Each functional group within the stream is within its own niche but is dependent upon other stream inhabitants for its existence. Because the streams are heterotrophic, the inhabitants are nearly totally dependent on riparian vegetation for their food source.

RIPARIAN VEGETATION AND SOILS

Riparian Vegetation Characteristics

What, exactly, is meant by riparian vegetation? Plant ecologists speak of it in terms of riparian species and plant communities. Moreover, it has been defined in terms of topography (Moss 1932), soils (Hanson and Smith 1928) and hydrology (Johnson et al. 1976). Actually, riparian vegetation is the interface or ecotone between aquatic and terrestrial environments. It is also safe to consider riparian vegetation as any extra-aquatic vegetation that directly influences the stream environment.

Because riparian vegetation is ecotonal it cannot be discussed as a separate entity. For that reason it was necessary to briefly discuss stream ecosystems and their function. Riparian vegetation is highly important to the aquatic ecosystem because it regulates the aquatic energy base through shading and organic matter input. Shading directly influences P/R ratios through regulation of stream temperature and light penetration. Riparian vegetation also provides a large degree of terrestrial erosion control through rooting habits of herbaceous and woody plants. Authors differ somewhat in establishing riparian boundaries, but Meehan et al. (1977) established riparian zones in the Pacific Northwest by including all flood-plain vegetation as well as trees on hillslope areas which shade the stream or directly contribute coarse or fine detritus to it (Fig. 5). These boundaries would include streamside vegetation found in mountain meadows of Colorado, Wyoming, and Montana as well as flood-plain vegetation found on the Missouri River in North Dakota.



RIPARIAN VEGETATION

SITE	COMPONENT	FUNCTION
above ground-above channel	canopy & stems	1. Shade-controls temperature & in stream primary production 2. Source of large and fine plant detritus 3. Source of terrestrial insects
in channel	large debris derived from riparian veg.	1. Control routing of water and sediment 2. Shape habitat - pools, riffles, cover 3. Substrate for biological activity
streambanks	roots	1. Increase bank stability 2. Create overhanging banks - cover
floodplain	stems & low lying canopy	1. Retard movement of sediment, water and floated organic debris in flood flows

Figure 5. Boundaries of the riparian zone (from Meehan et al. 1977).

General Descriptions

Riparian vegetation described herein is by accepted common names (Beetle 1970). Scientific names are listed in Appendix A, Table 1.

The attempt to describe riparian vegetation in these four States has not been a popular topic in the literature. For example, Blake (1945) spent a number of years exploring the Medicine Bow Mountains of Wyoming and described in great detail the zoological components of riparian communities. He classified the riparian vegetation into small and large streams; large, moraine and temporary pond communities; and wet meadow and willow bog communities. No mention was made of vegetation except that willows and aspen were present. Earlier, Carpenter (1940) tried to characterize riparian vegetation by stating that the plant dominants of the prairie-plains are limited by moisture conditions and are extensions of eastern upland dominants found in far western portions of the grassland but only in low, subclimax, and nonclimatic (edaphic) wet lowlands and ravines. Moss (1932) described the Parkland vegetation of Alberta and placed alkali flats, coulees, and other depressions into specialized habitat categories within the prairie. They were essentially ecotones between prairie and poplar vegetation within the poplar association. What he was describing was the woody draw habitat type commonly found in North Dakota, Montana, and Wyoming. These Canadian woody draws were dominated by wolfberry. On lighter soils silverberry was a codominant. (Other common shrubby species included rose and raspberry; forbs described were northern bedstraw and goldenrod; wheatgrass and other grasses were also present. Some of these species are found in woody draws of Montana and North Dakota near the Canadian Border.

The extensiveness of riparian vegetation could be seen in Ramaley's (1907) description of plant zones in the Rocky Mountains. He classified the flora into five zones based on altitude. The Plains Zone ranged up to 5,800 feet and trees and shrubs occurred chiefly along watercourses. Riparian vegetation of the Foothill Zone (5,800 to 8,000 feet) occurred as deciduous trees in the canyons and draws. Other riparian-related vegetation was not described until the Sub-Alpine Zone (10,000 to 11,500 feet) when he noted numerous ponds and bogs occurring along stream courses. Riparian vegetation was apparently abundant in the Alpine Zone (11,500 to greater than 14,000 feet). Ramaley (1907) observed numerous sedges and grasses and dwarf willows, but no other woody plants. Kuchler (1964) described the Colorado alpine meadows in more detail. Short grasses and sedges made up the majority of the vegetation.

Specific Range Site Descriptions

The four broad site classifications into which riparian habitats fall are wetland, subirrigated, saline lowland, and overflow. These are soil groups designated by the Soil Conservation Service as areas that can produce more herbage than ordinary range lands because of obvious superior soil moisture availability. Wetlands are lands where seepage, ponding, etc. raise the water table to above the surface during only a part of the growing season. The vegetation of these areas is not that of true aquatics. Subirrigated sites are those with an effective subsurface ground-water table and water rarely over the surface during the growing season. Saline lowlands may also be classified as subirrigated or overflow but are dominated by slat-tolerant plants and salt accumulations are apparent. Areas which regularly receive more than normal soil moisture because of runoff or stream overflow are designated overflow area.

These four classifications encompass the majority of riparian habitats common to Wyoming, North Dakota, and Montana. Each site exists in more than one physiographic location. For example, within Wyoming there are 14 land resource areas designated by SCS in which wetlands occur. Therefore, the specific site descriptions will be restricted to a general description of wetlands vegetation proceded by a broad physiographic description of their locations. This descriptive pattern will continue for the remaining range sites and states.

Colorado range sites are broadly delineated by SCS into meadows, swales, and overflows. Because of the topographic differences which exist between this and the other three States, each separation in altitude will be discussed. For example, under the meadows classification there are alpine, wet, salt, and sandy sites. The potential vegetational differences between these meadow locations are obvious.

Wyoming Wetlands

Wyoming wetlands are found in every major land resources area in the State. This includes the 12.7- to 22.8-centimeter precipitation zone, and 1.128- to 1,830-meter elevation of the Big Horn and Wind River Basins, through the 50.8-centimeter precipitation zone and 2.501- to 3.660-meter elevation of the Teton Range. The sites are located near springs, seeps, sloughs or lower parts of alluvial fans. This vegetation type is also commonly found in bottom lands, depressions, or adjacent to ponds, lakes, and springs. Topography of these sites is relatively flat, with slopes of less than 3%. The riparian vegetation of these very different physiographic areas is similar. Grasses and grasslike plants comprise at least 70% of each community. Forbs and woody plants together sometimes make up only 20% of the total composition.

Individual species are able to withstand long periods of submersion in water. Wetland soils are deep and poorly drained with water tables above the surface for part, but not all, of the growing season. The A horizon is commonly high in organic matter and soil texture ranges from sandy loam to clay loam.

Plant species found in Wyoming wetlands include the following grasses and grasslike plants: Nebraska sedge, tufted hairgrass, bluejoint reedgrass, northern reedgrass, and mountain bromegrass. Common forbs on these sites are arrowgrass, columbine, horsetails, monkshood, pale agoseris, waterleaf, and waterhemlock. Bog kalmia, currant, rose, water birch, and willows comprise the dominant woody vegetation. Willows become more dominant if the site is allowed to deteriorate. Each species listed above would not be found within each major resource area in Wyoming, but the plants are representative of wetlands vegetation.

The major use of these areas is domestic livestock and wildlife grazing and browsing. These wetland sites are also susceptible to misuse because of the hydric soil conditions. Production on these areas can exceed 6,720 kilograms per hectare (kg/ha) air dry weight in favorable years. An average stocking rate is 3.75 AUM's per hectare. These figures may appear high because they are near the optimum for each attribute. It must be remebered that wetlands are very restricted as to total area occupied. The reason for the large impact on wetland riparian habitat is now evident. The soils are hydric, therefore susceptible to trampling damage. The wetlands are small in total area, but highly productive. Wetlands attract large numbers of grazing/browsing animals and can often be a major zone of occupation. Mitigation of these impacts is a future topic of discussion in this paper.

Subirrigated Sites in Wyoming

Subirrigated sites in Wyoming, like wetland sites, are found within every major resource area in the State. Physiographic and topographic features are identical to wetlands because subirrigated sites are those located immediately adjacent to wetlands--away from the streambank. Soils on these sites are deep, characterized by a fluctuating water table, and are nonslaine and non-alkaline. Soil texture does not differ from that of wetland areas. On some sites mottling or gleying occurs within 0.5 to 1.0 meters of the surface.

The major grasses and grasslike plants of these sites vary slightly between northern and southern resource areas. Basin wildrye, Nebraska sedge, and tufted hairgrass are common in northern climates and higher altitudes. Big bluestem, indiangrass, little bluestem, and prairie cordgrass may dominate a site on the southern plains. The following forbs can comprise up to 20% of the total vegetation: American licorice, iris, clovers, flax, fleabane, and western yarrow. Because this ecosystem is less hydric than wetland sites, willows do not usually dominate these sites unless they have been disturbed. Chokecherry, rose, shrubby cinquefoil, and willows are shrubs commonly found in the higher precipitation zones of the higher mountains. Buffaloberry, hawthorn and even rubber rabbitbrush become more important in lower elevations.

Production on subirrigated sites is usually greater than on dryland sites, but les than on wetlands. Upper elevations can produce as much as 5,600 kilograms of air dry forage per hectare. This decreases to 3,360 kg/ha on subirrigated sites within the Green River and Great Divide Basins. An average stocking rate for these areas is 2.5 AUM's per hectare. The primary use of these sites is grazing and browsing. The upper elevations support a large number of moose. If the area becomes misused, thistle, Kentucky bluegrass, earlycup gumweed, and willows will begin to invade.

Wyoming Saline Lowlands and Saline Subirrigated Sites

The primary differences between these two sites lie not with the vegetation, but with the soils and location of the water table. Lowland sites usually have good drainage but are moderately to strongly alkaline. This may be only in subsoils below the normal rooting depth of herbaceous species (1 m), but well within the rooting depth of shrubs. Soil texture varies considerably and there may be some evidence of salt accumulation on the soil surface. Saline subirrigated sites are moderately to poorly drained with an alkaline or saline water table within the rooting depth of herbaceous as well as woody species. Both sites are located at all elevations. Another differentiation between these sites is that saline lowlands occur normally on lands which receive additional water from overflow of intermittent or perennial streams or runoff from adjacent slopes. The saline subirrigated sites are nearly flat and are located near streams, springs, or ponds which can supply water most of the growing season. All of the vegetation on these sites must be salt-tolerant.

The primary grass species on most of these sites is alkalai sacaton. Basin wildrye, western wheatgrass, Nuttall's alkaligrass, and inland saltgrass are also common on these sites. Forbs do not usually comprise more than 10% of the total community and may include phlox, aster, locoweed, and alkali seepweed. Greasewood, shadscale, and rubber rabbitbrush characterize the shrubs on saline sites. In areas of high (>38 cm) rainfall these sites could produce as much as 3,360 kg/ha of air dry material. However, on saline lowlands in the Big Horn and Wind River Basins, 560 kg/ha is considered good. The composition of the vegetation on most sites is still 70% grasses, but ground cover on poor sites ranges from 20 to 30%, while ground cover on better sites can reach 60%. Characteristically, cover in saline areas is approximately 45%.

Wyoming Overflow Sites

Riparian overflow sites are restricted to major land resource areas with greater than 25.4 cm of annual precipitation. They are found in the northern and southern plains, basins, and high-altitude mountains. All overflow sites receive additional water from overflow of ephemeral streams or runoff from adjacent slopes.

Soils on these areas are relatively deep (0.5 to 1.0 m to bedrock depending on the site). In addition, they are well-drained and moderately permeable. Soil texture varies from sandy loam to silty clay loam. Sandy clay loams and clay loams are characteristics of clayey overflow sites. Root penetration is usually deep.

Potential natural vegetation is predominantly grasses (>65%). The amount of forbs and shrubs varies with the major resource area. The vegetation regions of these sites can grossly be delineated into northern plains, foothills, and mountains located east and west of the Continental Divide.

Northern plains overflow vegetation is dominated by tall and midgrasses, which comprise 75% of the community biomass. Dominant grasses are basin wildrye, green needlegrass, and western wheatgrass. Big bluestem may be found on some sites lower than 1.403 meters in elevation. West of the Continental Divide, rhizomatous wheatgrasses such as streambank and thickspike will enter the community while east of the Divide slender wheatgrass and Columbia needlegrass are present. Phlox, fleabane, buckwheats, violets, western yarrow, and green sagewort are common forbs on all sites. The foothills and mountains west of the Divide offer a more diverse community in both forbs and shrubs than any of the aforementioned resource areas. Shrubs include chokecherry, big sagebrush, rose, serviceberry, silver sagebrush and snowberry. On the plains in upper elevations, hawthorn, chokecherry, and American plum can be found, while winterfat is common in the areas of lower elevation and lower precipitation.

Forage production on these areas is as variable as the vegetation, but an average figure appears to be 2,240 kg/ha air dry. Initial stocking rates are 0.75 to 1.0 AUM's per hectare. These overflow areas of Wyoming are similar to the woody draws in Montana in that they support a large number of deciduous shrubs. Therefore these areas tend to provide food and cover for a number of wildlife species. In rainy seasons these areas can also attract domestic livestock, making overflow habitats particularly susceptible to misuse.

North Dakota Wetlands and Wet Meadows

Wetlands are the most hydric sites within North Dakota. This site occurs on nearly level lake basins and depressions in glacial till plains. Soils are deep and very poorly drained. These medium- and fine-textured soils are primarily silty clays, silt loams, and silty clay loams. Soils on wet meadows are of the same general texture, but different taxonomic units. Topography of wet meadows is characterized by swales and depressions in glacial till plains, glacial lake plains, and outwash channels.

Grasses dominate wetland range sites in North Dakota. Sedges are considered subdominants. Plants characteristic of these wetland sites are adapted to wet conditions, but not so wet as to support marsh vegetation. Wetlands support a variety of grasses and grasslike plants. Included are rivergrass, prairie cordgrass, northern reedgrass, and slough sedge. Rivergrass is the dominant grass and production is approximately 2,240 kg/ha in the Coteau and Drift Prairie Vegetation Zones. The Coteau Zone extends from the extreme northwestern corner of the State above the Missouri River to the central portion of the State. The Drift Prairie extends from 101° to 102° longitude diagonally northwest to southeast across the State.

Rivergrass and prairie cordgrass are dominant grasses in the Missouri Slope Vegetation Zone. The Missouri Slope has the Missouri River as its northern border and encompasses much of the southwestern portion of the State.

In this wetland range site, sedges are considered codominants. Sunflower is the predominant forb and no willows are present. Total production from this riparian site approaches 5,600 kg/ha. This production figure is duplicated in the Coteau and Drift Prairie Vegetation Zones, but there appear to be more species, hence greater diversity, in the Missouri Slopes.

While wetland sites are dominated by grasses, wet meadow sites, especially in the Coteau and Drift Prairie Zones, are dominated by mid-sedges. Principal species are slim sedge and woolly sedge. Grasses, primarily prairie cordgrass and northern reedgrass, are subdominants in wet meadows. Dominant forbs in these two vegetation zones are American licorice and small white aster. The Coteau Zone does not support a significant shrub community; however, woods rose, western snowberry, and willows are found in the Drift Prairie. On the Missouri Slopes, wet meadows contain nearly equal amounts of grasses and sedges, but there are no species differences between this zone and the Coteau Zone. Production on all wet meadow sites is approximately 4,480 kg/ha.

Additional information concerning North Dakota wet meadow vegetation is provided by Dix Smeins (1967). Their study was conducted in northeastern North Dakota on the eastern edge of the Drift Plain immediately west of the Red River Valley. The area, glaciated during the Pleistocene, resulted in a topography with rolling plains occasionally interrupted by moraines, ponds, and small lakes and coulees.

Riparian vegetation was primarily found in the lowland meadows adjacent to marshes (Dix and Smeins 1967). Drainage in these areas was relatively slow, with standing water present during the spring. The less hydric sites on the meadows tended to contain large amounts of northern reedgrass and woolly sedge in association with species such as prairie cordgrass, Baltic rush and creeping spikerush. Reed canarygrass will tolerate a wide range of moisture conditions, so it may be found with these species or on slightly wetter sites.

On sites where standing water is more prevalent, rivergrass and slough sedge are commonly dominant species. Along the edges of marshes are bulrushes and cattails. Other important species in lowland meadows of northeastern North Dakota are American bulrush, mint, hemlock waterparsnip, germander, swamp knotweed, and ladysthumb knotweed.

Cattle grazing is the dominant use of these sites (wetlands and wet meadow). The perched water table in the spring makes some of the areas ungrazable at this time, but they are excellent summer and early fall sources of forage.

Wildlife native to these areas are nongame birds, mule deer, white-tailed deer, and waterfowl. Some waterfowl are permanent residents of these areas, as the soils are poorly drained and occasional ponding occurs on the surface. These are part of the prairie pothole region, an area noted as a primary breeding ground for ducks and geese.

Prairie Potholes

Prairie potholes are water-holding depressions, sometimes connected by small streams of glacial origin, that occur north of the Missouri in the Coteau and Missouri Slope Zones of North Dakota. These areas are sometimes overlooked as riparian areas, but they are a valuable source of water for livestock and wildlife. In addition, they are invaluable as waterfowl breeding grounds. Water supply to these potholes is from direct precipitation events, surface flow into the watershed, snowmelt, ground-water seepage. Water losses result from evaporation, overflow, and seepage outflow.

The vegetational composition is not unlike that of the wetland or wet meadow sites. However, production is only one half that of the other sites due to fine-textured soils. The pH of these soils is usually neutral on the surface but tends to be strong alkaline and sometimes sodic in the substrata. These soils are low in permeability, therefore ponding is common. Knowing the kind and amount of riparian vegetation near these potholes can indicate water permanence, depth, and salinity. Hydrologists realize that these are variables influenced by local ground-water flow system. Land managers should also be aware of this riparian response.

Riparian vegetation can be grouped into three distinct zones in the pothole region. These include wet meadow, shallow marsh, and deep marsh (Sloan 1970). Wet meadow zones consist of short-stemmed grasses or grasslike plants in shallow potholes or around edges of deep potholes. The wet meadow zone includes species such as fowl bluegrass, northern reedgrass, wild barley, saltgrass, and Baltic rush.

Medium-stemmed grasses and grasslike plants are found in the shallow marsh zone. Emergent species of this zone include tall mannagrass, giant burreed, slough sedge, sloughgrass, and spikerush.

Deep marsh zones are dominated by emergents and do not qualify as riparian vegetation. These plants include cattail and bulrushes. Although these plants are strict aquatics, they are widespread in the more hydric riparian systems and can contribute organic matter for stream decomposition.

The listing of these vegetation types and species by no means exhausts the plants found in riparian zones of the prairie pothole region. They only serve as an example of riparian vegetation which can be harmed if overused either by man's irrigation activities or by concentration of livestock.

Subirrigated Riparian Sites in North Dakota

Subirrigated sites in North Dakota are restricted to the Drift Prairie and Coteau Vegetation Zones. These sites are commonly found in depressions and drainageways near a high water table. Soils are somewhat poorly drained and are medium to fine textured. The shallow water table keeps the root zone moist during most of the growing season. These sites also commonly receive additional runoff waters from the adjacent watershed. Therefore, the water table can be below the root zone and the site can still be of a riparian nature. Permeability is relatively slow. Specific textures associated with these sites are clay, silty clay, and silt loams.

Tall warm-season grasses dominate the general appearance of subirrigated riparian sites. The principal species of both Drift Prairie and Coteau are big bluestem and switchgrass. Little bluestem and prairie cordgrass are also found in the Coteau Zone. Western wheatgrass is found in the Drift Prairie Zone in addition to little bluestem and prairie cordgrass. Cinquefoil and sunflowers are common forbs in both zones. Only the Drift Prairie Zone supports shrubs in the subirrigated sites, usually woods rose, western snowberry and willows.

Predominant use of the subirrigated lands is for grazing domestic stock and as food and cover for wildlife. Air dry production is approximately 3,920 kg/ha. Cattle are usually grazed in the summer on these riparian sites because of the dominance of warm-season grasses.

North Dakota Overflow Sites

Overflow sites occur in swales and depressions in glacial till plains and on stream terraces and flood plains. Only a general vegetative description of the understory will be discussed for these sites, as the overstory is typical of flood-plain vegetation previously described.

Drift Prairie and Coteau Vegetation Zones are similar in soils. Both zones have deep, moderately well-drained, moderately coarse- to moderately fine-textured soils. These and other overflow sites receive additional water from surface runoff from higher land or flooding. Soil texture on these sites is predominantly silt loam and loam in the Drift Prairie Zone. The Coteau Vegetation Zone soils contain more clay, as silty clay loams and clay loams are common. This may be the cause of certain vegetational differences.

The Drift Prairie Zone overflow sites are dominated by big bluestem. Other grasses in the zone are switchgrass, little bluestem, western wheatgrass, and needleandthread. These latter species are of equal proportion in the community but comprise a minor portion of the total landscape. Kentucky bluegrass is also a minor species until a disturbance or misuse of the area occurs, at which time this species can eventually dominate. Sunflowers, aster and goldenrod are found in the Drift Prairie riparian zones. Shrubs on these sites are predominantly fringed sagebrush, western snowberry, rose, chokecherry, and buffaloberry. Grasslike plants are a minor component of the overflow ecosystem.

Coteau vegetation types are similar with respect to forbs, sedges, and shrubs. Grass species are identical but in different proportions, on these sites, as are those in the Drift Prairie Zone. Warm-season grasses are not a dominant in the Coteau Vegetation Zone. Big bluestem is present, but green needlegrass, needleandthread, and western wheatgrass are in nearly equal proportions, probably due to heavier soil texture. Total production is approximately 2,800 kg/ha air dry in both zones. Both zones offer good grazing in the summer. Widlife habitat is the chief use, as the shrubs are particularly attractive to deer, small mammals, and upland birds such as sharp-tailed grouse, mourning dove, and redwinged blackbirds.

The overflow range sites in the Missouri Slope Vegetation Zone are similar to those of Missouri River flood-plain vegetation. These overflow riparian sites in North Dakota also include typical woody draw vegetation of the Missouri "breaks." Soils in depressions, flood plains, and coulee bottoms are deep and moderately well drained. The surface layer is made up of medium- and fine-textured materials. Runoff is commonly received in the spring in depressions but it is usually slow, as is infiltration into the soil. Soil textures in these areas are quite variable, including silty clay, silty clay loams, silt loams, and clay loams.

The understory is predominantly big bluestem, western wheatgrass, green needlegrass, and needleandthread. Several forbs, such as sunflower, tall goldenrod, and aster are common but usualy only make up about 10% of the total. Several woody plants are commonly found on the site, depending on their positions in the landscape. Shrubs and trees such as western snowberry, chokecherry, bur oak, green ash, American elm and quaking aspen are common in the coulees and flood plains. Fewer trees are found away from the Missouri River. In the badlands of southwestern North Dakota, aspen and deciduous shrubs dominate the overstory on overflow sites.

Total production on these sites is greater than 2,240 kg/ha, and livestock grazing is a primary use. Sites with more trees and shrubs provide food and cover for white-tailed and mule deer. Other wildlife species also make use of this riparian habitat. On overgrazed areas, western wheatgrass, blue grama, Kentucky bluegrass, and sedges will increase.

North Dakota Saline Lowlands

North Dakota saline sites are recognizable from salt accumulations on the surface of the soil. Soils are usually deep and poorly drained with medium to fine texture. These soils are typically saline and alkaline and receive additional water from seepage or runoff. These sites are located throughout the State and can be found in shallow basins, on lake and river plains, and on low terraces and bottom lands along streams. Soils of the Badlands, Coteau and Drift Prairie Vegetation Zones are commonly sodium-affected throughout the profile. Missouri Slope soils are typically saline and/or alkaline. Soil textures in all zones may include clay, clay loam, silt loam, silty clay, and very fine sandy loam.

All vegetation zones are dominated by salt-tolerant midgrasses. Nuttal's alkaligrass, western wheatgrass, inland saltgrass, slender wheatgrass and alkali cordgrass are the principal understory species. Forbs commonly found in riparian saline lowlands are silverweed cinquefoil, pursh seepweed, and western dock. Shrubs do not normally inhabit these sites, but dense stands of greasewood and saltbush may be found.

Summer cattle grazing is a common use of this site. Antelope and white-tailed deer will also consume forage on these sites. Production may exceed 2,240 kg/ha in a good year. Species which increase with grazing are western wheatgrass, mat muhly, and foxtail barley.

Montana Riparian Vegetation

Detailed discussion of the flood plain of the Missouri River, Rock Creek, and the Missouri River "breaks" will be postponed until later in this paper. The present discussion of Montana riparian vegetation will focus on the western mountains and foothills.

The mountains and foothills of Montana lie west of the cities of Billings and Great Falls. Elevation of this area can range from 610 to 3,355 meters. The topography is typically rugged and results in great environmental differences with short distances due to elevation, slope, and aspect. Riparian systems are primarily located within drainages. Most of the time the slopes are dominated by conifer forests. Bottom-land areas may contain aspen as the dominant overstory species. Only small shrubs and grasses may exist in dense, narrow drainages where canopy closure limits the light penetrating the understory.

Soils in these areas are not well drained and are medium to fine textured. Silty clays and silty clay loam soils are common. Runoff from precipitation and snowmelt supplement a normally high water table associated with wetland and subirrigated sites. Consequently, the vegetation found in these areas is of the more mesic type. Some soils in the foothills may be slightly saline to alkaline. Therefore, salt-tolerant grasses and some low-growing shrubs are frequently found there.

Saline lowland sites in mountainous areas are dominated by salt-tolerant grasses. Alkali sacaton, Nuttal's alkaligrass, slender and western wheatgrass, basin wildrye, and inland saltgrass are dominant species. Greasewood and silver buffaloberry are shrubs commonly found. Production on these areas can exceed 2,800 kg/ha and carry 3.0 AUM's per hectare. As grazing pressure becomes more intense, species which increase will include foxtail barley, bottlebrush squirreltail, poverty sumpweed, summer cypress, and rose.

Subirrigated and Wetland Sites in Montana Mountains

In the mountains and foothills the wetland sites are predominantly grasses. Reedgrasses, tufted hairgrass, and tall sedges are most commonly found. Shrubby cinquefoil, Indian paintbrush, monkeyflower, and native clovers are common forbs. Willows are located in poorly drained soils, while aspen may be located within the coulee, but farther upslope.

With grazing pressure a number of sedges and forbs may increase in the overflow areas. Up to 3,920 kg/ha may be produced in lowland depressions and a stocking rate of 3.75 AUM's per hectare is acceptable. These areas are particularly attractive to wildlife, especially elk, deer, and moose.

Colorado Riparian Swales

Colorado swales are typical of other depressions located in mountainous areas of the West. They are primarily located in the mountains and foothills where elevation ranges from 1,830 to 2,745 meters. These swales and valleys may include alluvial bottom lands; all of these sites receive runoff from adjacent uplands.

These swales are primarily grassland sites with minor amounts of forbs and shrubs. Dominant grasses are basin wildrye, slender wheatgrass, western wheatgrass, and streambank wheatgrass. Forbs include yarrow, fleabane, geranium, and globemallow. Snowberry, chokecherry, rose, dogwood, serviceberry, and willows are major shrubs within the mountains. At lower elevations within the foothills, big sagebrush and rabbitbrush are dominant shrubs. These two shrubs may increase in the mountains if grazing pressure is high. Small wet areas occur in the stream bottoms of the mountains and produce primarily sedges, rushes, and willows.

Deep, well-drained, medium- and moderately coarse-textured soils such as sandy loams and loams are found in both the mountains and foothills. Soil organic matter content is usually high. These soils have good permeabiity and high water-holding capacity.

Above-ground production in the areas ranges from 2,240 to 2,800 kg/ha of air dry material. Cattle grazing is a widespread use on more grassy sites, while sheep are favored on sites with predominantly forb cover. As with other riparian areas these sites are utilized heavily by wildlife, especially deer, elk, and upland game birds in the foothills.

Colorado Overflow Areas

Colorado overflow sites are typical of other Western overflows as they are typically located in swales, draws, valleys, and streamsides. These sites benefit from overflow waters moving onto the site from nearby rivers or streams or from runoff. This additional water is the reason for the riparian habitat.

There are basically two types of overflow areas in Colorado, and the vegetation on these sites is edaphically controlled. One of the vegetative types is called a normal overflow site. These soils are deep alluvials and are free from adverse salinity or alkalinity. Soils range in texture from sandy loams to clay loams. They also have a high water-holding capacity. Other overflow sites are either alkaline or saline and support the vegetation normally associated with these soils. The amount of saline or alkaline material in the soil will determine plant production. Soil texture on these sites ranges from loamy sands to clay loams. The water-holding capacity is normally high, but some sites in the San Juan River Valley or Pecos-Canadian Plains and Valleys are subject to erosion because of infrequent runoff.

Normal overflow sites will produce 2,800 kg/ha of air dry forage. Most of the production originates from switchgrass, western wheatgrass, blue grama, big bluestem and indiangrass. Forbs will not normally make up a large percentage of the total production. If the site is misused, summer cypress, Russian thistle, cheatgrass and Russian knapweed may invade. Fourwing saltbush may be present on these overflow sites.

Vegetation on saline or alkaline sites is dependent on the degree of salinity or alkalinity of the soils. For example, species on alkali overflows are primarily saltgrass, creeping wildrye, and rushes. Greasewood and fourwing saltbush are present in measurable amounts. Average production on these sites is 1,344 kg/ha of air dry material. Saltdesert overflow sites border on riparian classification, but they do receive run-in water from adjacent areas of the watershed. Alkali sacaton is present in large numbers on these sites. Subdominant grasses are galleta and basin wildrye. Fourwing saltbush and big sagebrush are the dominant shrubs on these sites and may at times comprise the majority of the vegetation. Saline overflow sites are found in most parts of Colorado other than the mountains. A mixed grass and shrub community containing alkali sacaton, switchgrass, and fourwing saltbrush typifies this site. Other grasses on these sites are western wheatgrass, vine-mesquite, blue grama, galleta, and sand dropseed. The sites are relatively poor with respect to above-ground production (1,456 kg/ha). This is largely due to a 25.4- to 48.3-cm precipitation zone and highly erodable soils.

Colorado Meadows

Colorado riparian meadows are found in nearly all portions of the State. Riparian meadows are relatively flat areas with mild depressions and basins. Both overflow and subirrigation characteristics are evident on these sites, but meadows differ from swales in that they are not within coulees or large drainages. Both water availability and soil salinity affect vegetational composition. Therefore, wet and alpine meadows are readily distinguishable from salt meadows.

Alpine meadows are found in precipitation zones of 63.5 to 114.3 centimeters at 3,507 to 4,270 meters. These riparian areas have a very short growing season and permafrost occurs in some alpine areas. A dense cover of willows, coarse sedges, tufted hairgrass, and alpine timothy characterize this site. Forbs such as cinquefoil and elephanthead pedicularis are also present in small numbers. Approximatley 1,680 kg/ha of air dry forage can be produced on there soils, which vary from gritty loams to gritty sandy loams. A black fibrous peat mat of variable thickness may overlie these soils. The soil is poorly drained, gleyed, and high in organic matter. The vegetation is limited by high winds, slightly acidic soils and to those species tolerant to low phosphate fertility. Alpine meadows are often inaccessible to cattle, and wildlife have relatively little cover on these sites. Environmental conditions such as these make reclamation after disturbance very difficult.

Wet meadows in Colorado exist in high intermountain valleys (elevation, 2,287 to 2,592 m; precipitation, 15.2 to 25.4 cm) to the central high plains and table lands (elevation, 915 to 1,830 m, precipitation, 33.2 to 48.3 cm). The high intermountain wet meadows are therefore relatively flat areas near flowing streams and are dependent on subirrigation and overflow. Wet meadows in the central plains area are dependent upon local precipitation and a bottomland location for their riparian charcteristics.

Soils in the intermountain wet meadows have developed on alluvial deposits under the dense grass cover. Most sites have moderately deep soils with a dark-colored clay loam to sandy loam surface high in organic matter. The central plains wet meadow sites are underlain by predominantly sandy soils and range from deep to shallow depending on the water table. Salt content of both wet meadows soil types discussed here is minimal and not a restriction to plant growth.

Grasses and grasslike plants make up most of the plant cover on intermountain wet medows. Tufted hairgrass and Nebraska sedge are dominant on the wetter sites. Slender and western wheatgrass are predominant on the drier sites. Forbs do not comprise a major portion of the community, but American vetch, native clovers, common licorice, western yarrow, and waterhemlock can be found. Alkali sacaton and mat muhly may be present along edges where salt meadows intergrade. Production on these sites may exceed 2,800 kg/ha of air dry material. Cattle grazing is common in the intermountain area, and the wetter areas support large waterfowl populations.

Central high plains wet meadows exhibit a difference in vegetative dominance chiefly because the high water table puts moisture within easy reach of plant roots the major part of the growing season, making conditions favorable for both warm- and cool-season grasses. Tail warm-season grasses make use of this additional moisture and dominate the landscape. Switchgrass, big bluestem, prairie cordgrass, and indiangrass are warm-season grasses which make up most of the vegetation on the site. Sedges and rushes are minor components, as are forbs. Shrubs such as rose and snowberry occur inconsistently. These sites, produce up to 2,800 kg/ha of air dry material and are heavily utilized by cattle and grazing and browsing wildlife. Waterfowl also make use of nearby streams. Because of easy access and high production, these areas are susceptible to overuse. Plants not a part of the native community that are most likely to invade when the cover deteriorates are summer cypress, American elder, greasewood, and rabbitbrush.

Salt meadows are located throughout Colorado, typically in mild depressions between main streams, and may be found as high as 2,531 meters. Salt meadows may form an ecotone between wet meadows and salt flats. As in other parts of the Western United States the riparian vegetation is limited to those species with variable amounts of saltwater tolerance. Salinity and alkalinity in the salt meadow soils are variable. Surface texture may be loamy or silty clay loam, and some salt crusting may be evident on the surface.

Forbs form a minor component of the vegetation. Salt-tolerant grasses such as inland saltgrass, alkali sacaton, alkaligrass, western wheatgrass, and basin wildrye comprise most of the vegetative community. Sedges and Baltic rushes can be found in more hydric areas. Greasewood is the only shrub native to these sites, but rabbitbrush may occupy some niches. Forage production ranges from 1,680 to 2,800 kg/ha and livestock grazing is a major use. Because of the low forb and shrub cover those areas are not considered valuable wildlife habitat for big game animals. Rabbits and upland game birds may be frequently found.

The final Colorado riparian meadow to be discussed is the sandy meadow. This site is typical of a riparian rangeland site on the Colorado central high plains and table lands. Elevations range between 1,372 to 1,982 meters. This site occupies the wet areas along streambeds, below permanent springs, and in valleys with a high water table. It is often used for hay production. Average air dry biomass is 2,800 kg/ha of predominantly warm-season grasses. The sandy soils support a water table within 3 feet of the surface. Below this depth a mottling or a gley saline layer may appear in the soil. Therefore, if the area is misused, salt-tolerant species may increase on these sites. These areas are often streamside meadows supporting stands of cottonwood.

The vegetation is dominated by tall, warm-season grasses, principally switchgrass, indiangrass, sand bluestem, prairie sandreed and, on the wetter sites, prairie cordgrass. Sedges and rushes may also be present as a minor understory component where water is at or near the surface for a significant portion of the year. Wild rose may also be found in these sandy bottom lands.

The Missouri River

The "Breaks"

While there are few studies specifically describing riparian vegetation, other research has described the vegetation of the study area. Such is the case with a wildlife study by Mackie (1970) in the Missouri River breaks region of north-central Montana. The "breaks" region is the area along the Missouri River characterized by ridges, coulees, and creek bottoms resulting from erosion of a broad plateau sloping north to east. The breaks are confined closely to the river region, and rolling plains extend away in a sharp ecotone (Fig. 6). Riparian vegetation is confined to the woody draws of the numerous coulees in the area. Alluvial soils of the Havre silt loam and Lohmiller clay loam series predominate in the bottom lands. Soils on other areas are derived

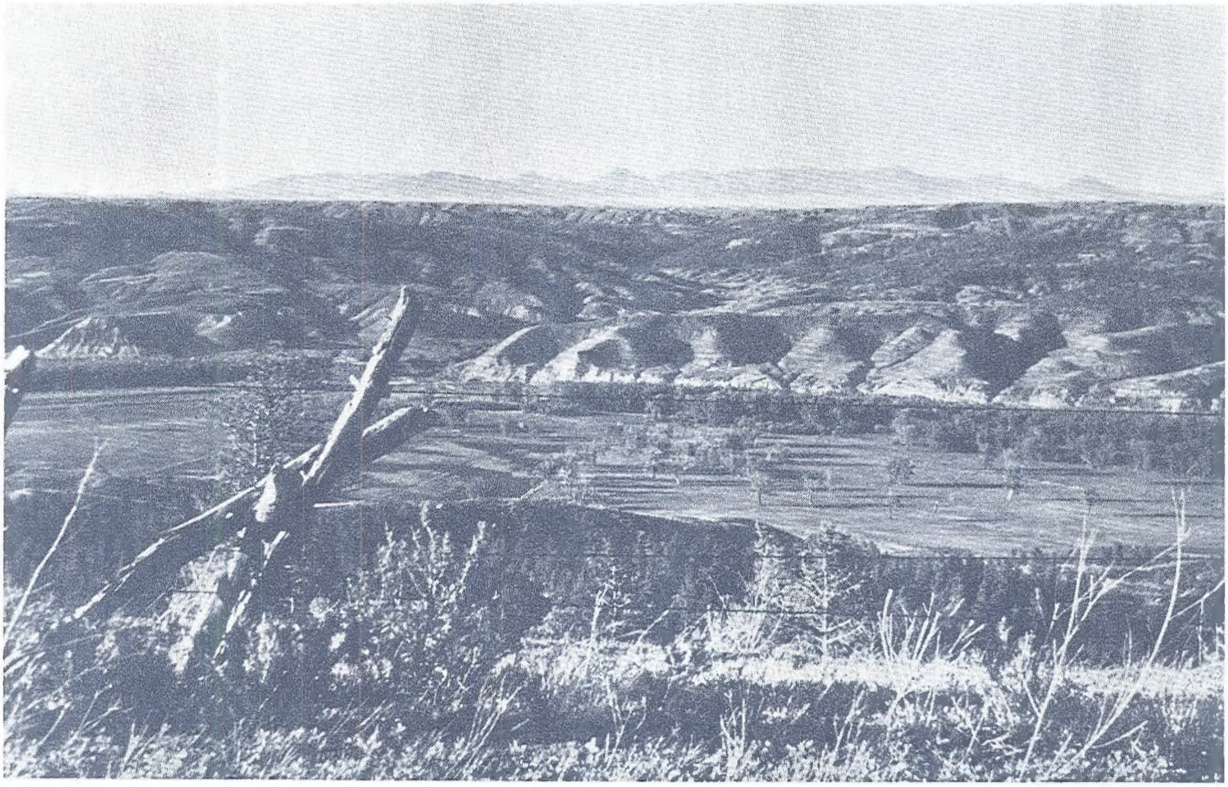


Figure 6. Riparian vegetation in the Missouri River breaks ranges from the coulees to the river's edge.

from Bearpaw Formation, which consists largely of clay shale containing moderate amounts of alkali salts. These are predominantly heavy clay loams of the Lismas and Pierre series (Gieseker 1938).

The breaks area is a mosaic of vegeation patterns. For example, slopes can be dominated by a Douglas-fir/Rocky Mountain juniper association, a ponderosa pine/Rocky Mountain juniper/bluebunch wheatgrass association, or a longleaf sagebrush association. These associations will usually approach the riparian areas but will not dominate a bottom land. Whenever dispersed clay soils containing high amounts of sodium occur, the vegetation is sparse and dominated by greasewood. These sites are usually located along footslopes, Missouri River bottom lands, and low benches along larger coulees. This is not usually thought of as a riparian type but could be considered flood-plain vegetation in sodium-dominated soils. The major grass species in slightly sodic soils is western wheatgrass. Occasionally, big sagebrush and bluegrass will codominate with greasewood and western wheatgrass on less sodic sites. Species of the bluegrass union may predominate during the spring in some areas. Plants (forbs) of this union will include the wild onion, lomatium, musineon and spindle plantain. In the summer the following forbs of the Tragopogon union are common: bastard toadflax, plains pricklypear, scarlet globemallow, common salsify, and American vetch.

Another coulee bottom habitat is that of the Agropyron-Symphoricarpos type. This habitat is minor in extent in this area but the soil type on which it occurs, silty clay, is typical of flats adjacent to watercourses in the Northern Great Plains. The site can be recognized as a wet meadow dominated by western wheatgrass and Canada bluegrass. Saltgrass is found on saline sites nearer the watercourse. Western snowberry, silver sagebrush, green rabbitbrush, and Arkansas rose are common shrubs. Wild licorice and members of the Tragopogon union typify the forb community.

Woody draws in this area also contain members of the Xanthium habitat type. This species and its associated union members are located on cuts or beds of intermittent watercourses where the shale, silty clay, or gravelly substrate is typically moist and alkaline. The vegetative growth in this area of the Missouri breaks is sparse and is dominated by cocklebur. Canada wildrye, prairie cordgrass, and foxtail barley are typical grasses on these areas. However, their range is edaphically controlled through silty clay deposits. Interspersed within the Xanthium habitat type are numbers of the Agropyron smithii-Symphoricarpos unions including saltgrass. Spike sedge and/or alkali bulrush will inhabit areas of standing water.

Other plant communities which occur away from the woody draws and coulees but still depend on above normal amounts of subsurface water, are those of the Populus-Symphoricarpos type. Plains cottonwood dominates the overstory and western snowbery and shrubby understory. Also found is a willow type. Dense thickets of these trees are comprised chiefly of sandbar willow, Bebb willow, and MacKenzie willow. These two types are characteristic of the Missouri River bottom land in Montana adjacent to the actual breaks.

The Flood Plain

The flood plain along the Missouri River in north-central Montana usually begins abruptly where the breaks terminate. The flood plain can vary up to a mile in width. The soils of Missouri River flood plains vary widely in texture due to flooding (Omodt et al. 1968). Silts, sands, and clays were present in various thicknesses, and profile development on this type of flood plain was minimal, with only A and C horizons usually distinguishable. The four basic soil series on the Missouri flood plain are the Banks, Havre, Lohmiller, and Gallatin.

Allen (1968) outlined four major vegetation types found on the flood plain: cottonwood, meadow, greasewood, and weed. Willows were located in dense patches along the flood plain but were not included in the dominant classifications. The greasewood type occurred next to the slopes, the cottonwood type next to the river, and the willows on the downstream side of sandbars. The meadow type was arranged more generally and fields of weeds dominated some areas as a result of flooding or abandonment. The following paragraphs list dominant species within these riparian flood-plain vegetative types.

Plains cottonwood dominated the cottonwood vegetation type (Fig. 7). The only other trees recorded were boxelder and peachleaf willow. Nootka rose and western snowberry were dominant shrubs. Grasses within this habitat type were Canada wildrye, western wheatgrass, and smooth bromegrass. Cocklebur and indianhemp were common forbs.

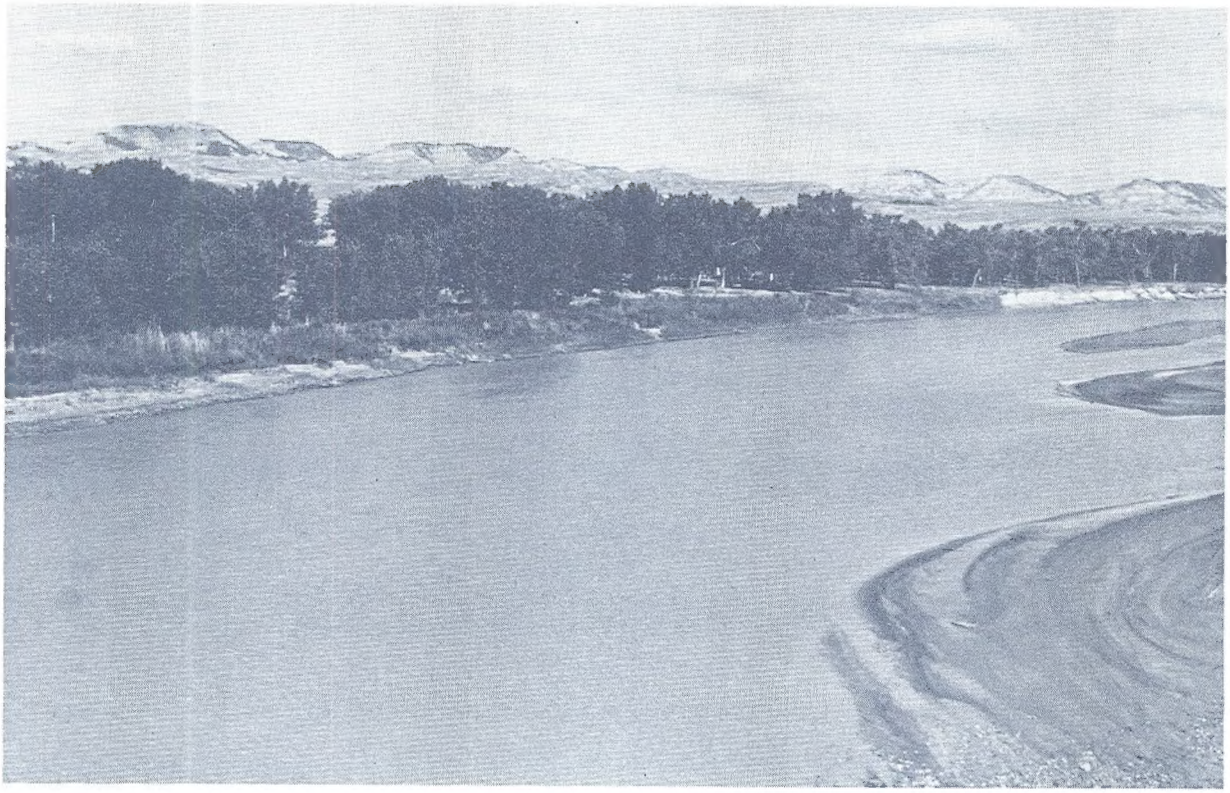


Figure 7. Plains cottonwood is commonly found in the Missouri River flood plain.

Slopes and footslopes were occupied by greasewood 1 to 1.5 meters tall. The genera found on this site were not unlike those described by Mackie (1970), but some species were different. Silver sagebrush, green rabbitbrush, and Nootka rose were other shrubs on the greasewood area. Forbs noted on these sites were chiefly prairie pepperweed, lambsquarters, spindle plantain, and erect knotweed. Primary grasses were Canada bluegrass, western wheatgrass, and Sandberg bluegrass.

Meadow vegetation was dispersed throughout the flood plain and contained only grasses and forbs. Western wheatgrass was the only grass placed in Allen's (1968) meadow classification. Predominant forbs included littlepod false-flax, summer cypress, prairie pepperweed, and erect knotweed.

Weedy species were located chiefly in abandoned or disturbed areas along the flood plain. A large number of cottonwood seedlings were found on these sites and placed in the weed category. The grass green bristlegrass and barley were also considered weeds by Allen (1968). Those forbs considered weeds were prostrate pigweed, geum, lambsquarters, and dandelion.

It is interesting to examine the different plant classifications of various authors. The classifications by Mackie (1970) and Allen (1968) are not totally unlike. It must be remembered that Mackie was describing woody draws inhabited by elk and mule deer while flood-plain vegetation was being described for a white-tailed deer study. Kuchler (1964) classified the total Yellowstone/Missouri River vegetation into a northern flood-plain forest. He stated that the forest was a cottonwood-black willow-American elm-dominated habitat throughout Montana and North Dakota. Neither Mackie nor Allen mentioned black willow or American elm. However, American elm was found farther downstream in North Dakota.

Flood plains along the Missouri River in North Dakota which were once considered pristine are now inundated by dams and reservoirs, which has caused considerble change over time in the flood-plain vegetation. Two studies recently described the forest over-story vegetation and Missouri bottom-land forests of North Dakota, located in a 130-km strip of remnant native vegetaion unaffected by reservoir activity in west-central North Dakota. Specifically, the area is located between Garrison Dam and Oahe Reservoir near Bismarck. The vegetation is typical of that located in all of North Dakota within the Missouri River flood plain. Information concerning the flood-plain forest overstory is taken from Johnson et al. (1976), while bottom-land forest data are from Keammerer et al. (1975).

The soils in this area have been briefly outlined by Gieseker (1938) and also described by Omodt et al. (1968) as silts, sands, and clays in variable thicknesses in the profile. The initial point bar is overwhelmingly sandy. The profile on the flood plain is not well developed due to depositional characteristics of flooding. Vegetation has little time to influence soil development between floods.

The Missouri River valley has been formed into a valley floor and three terraces. Drier upland sites are a mixed grass prairie type and are predominantly wheatgrasses, needlegrass, little bluestem, and blue grama. As the area becomes more mesic, large (presumably subirrigated) trees predominate. Among them are bur oak, American elm, green ash and boxelder. Cottonwood and willow predominate in the bottomlands. Within the valley floor and the first terrace three other woody species, chokecherry, buffaloberry, Russian olive and hackberry occasionally attain tree size (Johnson et al. 1976).

Green ash, cottonwood, boxelder, and American elm were the major overstory dominants in the flood plain. Johnson et al. (1976) found that neither peachleaf willow nor bur oak dominated in either terrace. The understory of these forests was quite diverse. Shrubs and vines included dogwood, wolfberry, poison ivy, chokecherry, woods rose, juneberry, wild grape, and Virginia creeper.

The bottomland supported a diversity of species too numerous to mention in this paper. The diversity of this and other riparian areas was demonstrated by Keammerer et al. (1975), who statd that bottom-land forests contain 50.9% of the families, 29.3% of the genera, and 19.2% of the species found in North Dakota. Compositae had the most species representatives (36), followed by Poaceae (26 species). Cyperaceae, Leguminosae, Labiatae, Rosaceae, and Ranunculaceae each had 10 or more species represented in the bottom land.

After discussing streamflow it is evident that wildfire, clearcutting, or even animal-induced disturbances will cause the vegetation to alter its normal successional development. Odum (1971) has stated that riparian succession is due to interaction of allogenic and autogenic influences--that is, influences created by the vegetation in situ or outside influences. We will now examine how the lateral action of the Missouri River strongly influences the type of vegetation present. Some of these principles are applicable to meandering streams as well.

When the river meanders it deposits alluvium on the inside of river curves while on the opposite side it erodes away established banks. These banks are often inhabited by flood-plain forest vegetation in different stages of development. The newly deposited alluvium is desirable for establishing pioneer tree species. These will only include cottonwood and willow seedlings, as other potentially dominant species cannot colonize. In fact, the proliferation of cottonwood and willow is dependent upon this alluvial deposit, because these trees cannot reproduce in stands where they are overstory dominants (Johnson et al. 1976). Thus, in order for species such as boxelder to become established, the river must avoid a site, allowing it to become less hydric. Where the river moves in a systematic fashion, a gradient of forest vegetation is produced with the younger cottonwood and willow stands nearest the river.

Research by Watt (1947) showed that neither cottonwood nor willow established seedlings in forest openings following disturbance. Hence they were totally dependent on river alluvium for seed germination and, in this respect, could be considered pioneer species. Johnson et al. (1976) found that along the Missouri River flood plain cottonwood and willow density was greatest in younger forest. Total density of these forests declined with age while average tree size increased as a result of intraspecific competition. The other predominant overstory species--i.e., bur oak, American elm, boxelder, and green ash, all have the capacity to germinate under the cottonwood-willow overstory, eventually replacing these species.

The Rock Creek Flood Plain

Soils and Vegetation

Rock Creek is located in south-central Montana near Red Lodge. It is a relatively small flowing stream whose flood plain is composed of four physiognomic strata. The dominant overstory species is black cottonwood. Soils along the creekbed are shallow, gravelly and noncalcareous. The first 8 centimeters of flood plain soil are composed of a dark grey loam with weak, fine-granular structure. Down to 43 centimeters the soils are a dark brown clay loam with prismatic to blocky structure. Below 43 centimeters flood-plain soils are a brown, gravelly clay loam; rocks are primarily granite, quartz, and argulite. The pH of all these layers is approximately 6. Tuinstra (1967) started that there are areas of deep, dark-colored alluvial soils that have a mollic epipedon for 30 centimeters over a stratified substratum for 25 to 76 centimeters.

The remainder of this discussion will center on the flood-plain vegetation and the temporal development of soils and vegetation. Although this location is in Montana, it is very near the northern Wyoming border. This vegetaiton type is typical of that found on similar, mountainous riparian areas in Colorado, Wyoming, and North Dakota.

Undisturbed vegetation at Rock Creek is dominated by cottonwoods up to 40 m tall. Aspen is sometimes considered a codominant. Other tree components are Douglas-fir, lodgepole pine and ponderosa pine, but these are considered subdominants. The tall shrub stratum occupies the stratum 2 to 6 meters above the ground and contains the species redosier dogwood, willows, chockecherry, water birch, and alder. Low-growing shrubs (less than 1 meter tall) include prickly rose, snowberry, and red raspberry. Common understory plants include such grasses, grasslike plants and forbs as bluejoint reedgrass, redtop bentgrass, Kentucky bluegrass, cutleaf coneflower, sedges, and horsetail.

The shrub community described in the above paragraph was part of the shrub streambank community of Montana described by Morris et al. (1962) who stated that of the shrub communities extending downward from the subalpine forest to the grasslands, those of streambank communities were the only ones which exhibited dominance or permanence. This permanence is essential to overall riparian habitat existence (Fig. 8). Zonation of shrubs was also quite evident. Hudsonian currant, alderleaf buckthorn, black elderberry, and bearberry honeysuckle are associated with upstream sites in the Douglas-fir/ponderosa pine-type habitats. Intermediate elevation sites are dominated by paper birch and black cottonwood. Streambank shrubs within a grassland habitat type are, in addition to the low-growing shrubs at Rock Creek, hawthorn and serviceberry.

While Morris et al. (1962) found hawthorn common in riparian areas within grasslands/woody draws, Tuinstra (1967) found hawthorn only in areas near Rock Creek that had been heavily grazed by cattle. Other vegeation changes induced

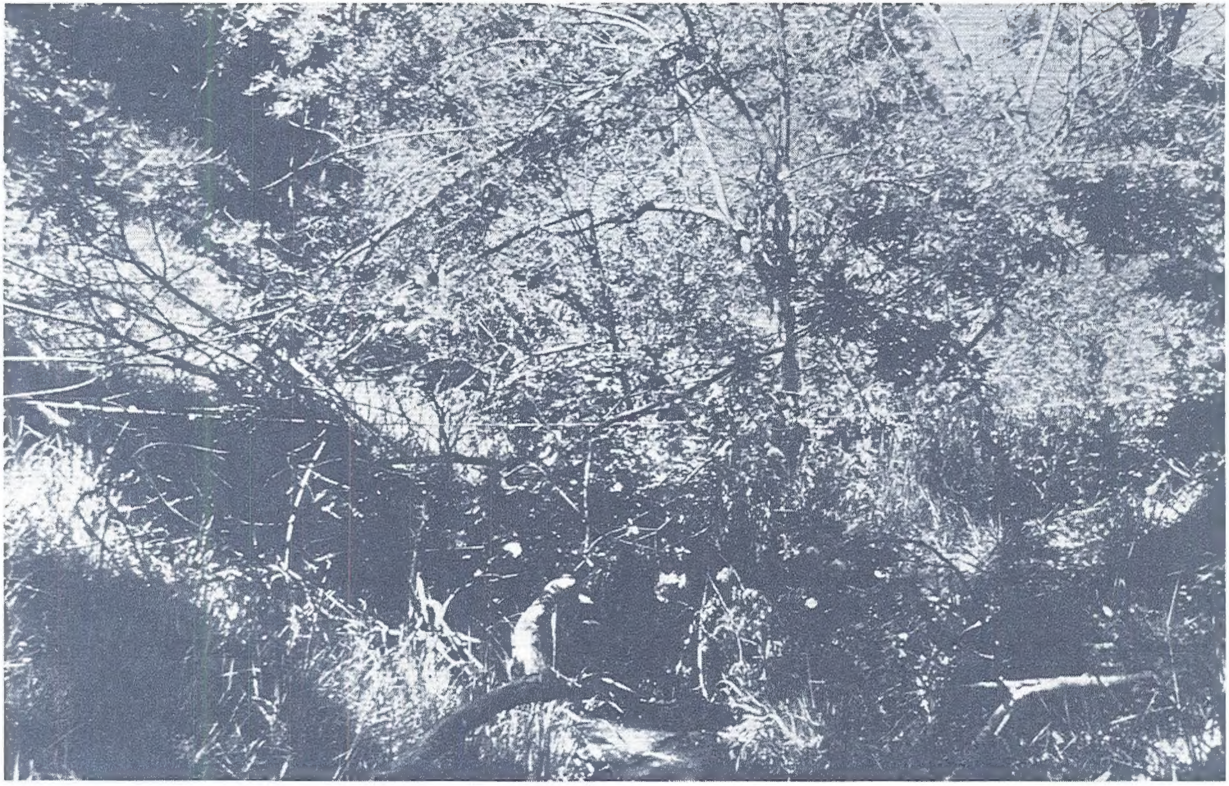


Figure 8. Dense shrub thickets, common in riaprian areas of south-central Montana, restrict cattle access.

by livestock at Rock Creek included near takeover of the grassy understory by Kentucky bluegrass. Other forbs found in the grazed area not present in the undergrazed area included dandelion, small hop clover, common plantain, white clover, bull thistle, and sticky cerastium.

Flood Plain Succession

Riparian flood plains in more mountainous regions of intermediate elevation (1,738 m) are commonly surrounded by a coniferous community on hillsides, a deciduous community within the flood plain, and a grassland community nearer the stream. Following a drastic disturbance, streambank vegetation may phenologically develop more rapidly than communities more upslope. Shading of the stream after a disturbance is valuable for reestablishing aquatic floral and faunal populations. Meehan et al. (1977) explained that deciduous shrubs and trees within the riparian zone will contribute most of the litter inputs during early watershed recovery. The deciduous litter decomposes more rapidly than the coniferous litter, which contributes substantially to the riparian litter base at later stages of succession.

The successional development of mountainous riparian zone vegetation is one of a predominantly grassland/shrubland mosaic followed by a stand dominated by deciduous trees finally terminating in a coniferous overstory, a deciduous shrub stratum and herbaceous ground cover. These seral stages also involve a shift in the stream's energy base from algae to herbaceous and deciduous leaves to a combination of herbaceous, deciduous, and coniferous leaves. Thus, streams flowing through older stratified forests would receive a more diverse energy input than those flowing through an area under a chronic disturbance such as grazing livestock.

A less general characterization of the flood plain seral stages at Rock Creek begins with a pioneer stage, continues into a young cottonwood and cottonwood-willow stage and, as the area becomes more developed, a young forest is formed and finally a mature forest. Some of the species to be documented were listed in the discussion of the four vegetative strata, but Tuinstra (1967) noted that the following species appeared to be restricted to the pioneer stage: rough bentgrass, whitecockle campion, lambsquarters, American speedwell, flannel mullein, bladder silene, and American wintercress.

As in the Missouri River flood plain, cottonwood was the first woody species to invade sparsely vegetated areas at Rock Creek. The young cottonwood stage is predominantly black cottonwood saplings less than 2 meters tall. Important forbs species found at this seral stage are: spotted knapweed, yellow toadflax, whitecockle campion, bull thistle, flannel mullein, baby goldenrod, and michaux sagewort. There is no sharp ecotone between the young cottonwood and cottonwood-willow seres. The only distinction is between the presence of willow and other species due to more mesic conditions. Tuinstra (1967) stated that flood-plain vegetation was apparently more dependent upon the quality, quanity, periodicity, and distribution of ground water for successional development than upon precipitation *per se*.

Herbaceous species become more numerous and diverse in the cottonwood-willow stage. Forbs occurring more frequently in this stage than in other seres include common monkeyflower, woodland forget-me-not, European strawberry, and field mint. Redtop bentgrass was the predominant grass.

Tall trees of the mature forest have already been listed as dominant overstory species. The natural successional pattern of the cottonwood and flood plain has already been pointed out. A chief reason for this is that cottonwood is not shade tolerant. However, it continues to dominate at Rock Creek due to such compensating factors as soil type and water availability.

There is little clay content of flood plain soils even in mature forests. The major textural component of all the flood-plain soils near Rock Creek is sand. However, these soils showed an increase in silt content with age in the upper 20 centimeters. The improvement of the water-holding capacity was evident in the mature forest sere. The mature forest also exhibited more profile development than any other seral stage. Taller shrubs represented in the mature forest were chokecherry, hawthorn, and serviceberry. Rose and snowberry comprised the shrubby undergrowth. Herbaceous vegetation was generally characteristic of drier sites within the mature forest. Kentucky bluegrass, spotted knapweed, hoary tansyaster, western goldenrod, American licorice, Pacific lupine, rose pussytoes, and poverty oatgrass were the prevalent species.

Habitats for the initiation of primary succession in the flood plain of either Rock Creek or the Missouri River are largely caused by flooding and are generally near the stream. In other words, the riparian environemnt is prime successional habitat. Initially, succession is governed by external factors--e.g., flooding (allogenic succession)--but as time passes, the plants alter their own environment by introducing more trophic levels and more complex nutrient cycles. Energy becomes increasingly more tied up in plant biomass. Plants essentially alter their own habitat such that they cannot survive (autogenic succession). More diverse seral stages are formed by this successional process.

Although the preceding paragraphs have listed successional changes on the Rock Creek flood plain, much the same processes occur on the Missouri River flood plain. Albertson and Weaver (1945) studied the recovery of overstory species on the Missouri River following drought. They, too, found cottonwood seedlings among the first two secondary seral stages. The pioneer species were mostly herbaceous, but cottonwood soon invaded the sites. Willows were present in later stages, but only in patches according to soil moisture. Trees typical ofthe Missouri River flood plain, such as boxelder and elm, appeared soon after cottonwoods had started to mature.

Succession then is a progressive development of one community to another. Some factors which effect this development are changes in diversity, stability, productivity, self-maintenance, and soil maturity. These factors will influence succession on all riparian habitat types regardless of the extent of their disturbance.

Site Description Significance

There are several reasons for giving brief descriptions of riparian habitats in Colorado, Montana, North Dakota, and Wyoming. The primary purpose is to acquaint the land manager and reclamation specialist with the diversity and breadth of riparian vegetation. Riparian vegetation is found in every major resource area associated with above-normal amounts of available water. Riparian vegetation is located in altitudes ranging from 610 to 4,270 m and in all precipitation zones. A wide range of soil textural classes is also represented. Riparian vegetation is found on river flood plains, woody draws, near mountain streams, and alpine wetlands.

There are four broad range site classifications into which most riparian areas fall: overflow, subirrigation, saline lowlands, and wetlands. Even the meadows and swales of Colorado could be classified under one or more of these broad range descriptions.

Vegetation on these sites is limited by the water table or salinity or alkalinity of the soil. Saline vegetation is relatively consistent throughout these four States and edaphic conditions are a vegetation-limiting factor. The water table is not a limiting growth factor on riparian sites. This contributes to the poorly drained characteristic of most riparian soils. It must be remembered that these soils and the vegetation on them are not extensive in total area. Their habitats are limited by water availability. At times these riparian areas form ecotones between hydric and semiarid upland sites. Soils and vegetation are particular to riparian sites and any attempt to characterize them as synonymous with surrounding ecosystems must be viewed with skepticism. There may be gradual gradients into the next vegetation zone, but the soils of the riparian zone will not be the same as those of the surrounding terrain.

I have briefly mentioned the primary endemic users of riparian habitats during discussion of the vegetative site descriptions. These users are influenced by the vegetation present on the site in terms of production and cover. The users, primarily livestock, big game, waterfowl, and upland birds, also interact with one another. Because the riparian habitat is attractive to many species, it can become abused. Overgrazing and trampling contribute to riparian vegetation degradation, which in turn affects stream water quality. This adverse trend continues into the detrital food chain spoken of earlier and fish habitat is eventually altered. The next major section will examine these users and the impacts on the terrestrial and aquatic ecosystems.

USERS AND IMPACTS

The use and users of riparian habitats are many. As early as 1960 McArdle listed several watershed management aspects of land uses and cautioned against potential abuse. One must realize that riparian ecosystems are a part of the total watershed, and management or use of the sytems are a part of the total watershed, and management or use of the riparian section will affect the whole management area. Four basic objectives should govern the integral use of the watershed: maintenance of an effectual plant cover, soil stability, maximum infiltration rates, and control of surface runoff. These are also primary considerations if a watershed is to be reconstructed after mining. Past and continued degradation of riparian areas has resulted in conditions which adversely influence water quality and quantity, commerical and recreational fisheries, aesthetics, and fish and wildlife values. Protection of stream riparian and wetland habitats should occur when necessary to preserve or restore fisheries, wildlife, water quality, and other values unique to these habitats. The protection and management of these areas are of particular concern because of the scarcity of these resources in many areas of the Western United States. These areas are becoming increasingly vulnerable to degradation as competing land uses and actions (i.e., overgrazing, dredging, water salvage, mining, road construction, and logging) increase. The next few topics will discuss the impacts of various users on the attributes of riparian ecosystems.

Impacts on Water Quality

As man's activities within riparian systems increase, his influence on water quality within the watershed will be greater. His activities include water development and irrigation, road construction, urbanization, timber harvest, recreation, and mining. The result of these actions can bring about a significant decline in water quality and aquatic faunal populations. But as Kibby (1978) stated, the effects of man's activities on the water quality of a given wetland depend on the hydrological characteristics of the area.

Forest cultural practices affect the quantity and timing of streamflow. Total volumes of flow tend to increase relative to unlogged areas (Megahan 1975). In areas of large snowmelt, flow volumes may increase during the snowmelt period. On some watershed, rainstorms occurring at the end of the growing season tend to increase peak flows on logged vs. unlogged areas.

Other attributes related to water quality and logging include increased sediment loads and stream temperature. It is obvious that with reduced vegetative cover, surface erosion, mass erosion and channel erosion will create mineral sediments in streams. In addition, without the benefit of shading, stream temperatures will increase. Debris and nutrients also result from logging. Buffer strips of undisturbed vegetation between the stream and adjacent logged areas can substantially reduce flow of nutrients, sediment, and debris into the stream and provide a stable stream temperature range. If buffer strips are not provided, the result is often debris damming the stream, fish migration blocks, decreased dissolved oxygen concentrations, increased nutrient and sediment inputs, and increased toxic substances leached from decomposing material.

Road construction for timber harvest or mining exploration also has a high potential for adversely affecting riparian systems. Access roads disturb many acres each year. Unfortunately, most roads are constructed near streams. Increases in overland flow, oil pollution from pavement runoff, and sedimentation of the bottom substrate results form alteration of the vegetative complex, the increased disturbance from vehicular traffic, and alteration of stream channels.

Man-made channel alterations include channel relocation, riprapping, channel clearance, and diking. These activities can be extremely detrimental to local fish populations (Fig. 12). Peters and Alvord (1964) surveyed 768 miles of Montana streams and found that altered channels do not support nearly as many fish as natural meandering channels within properly managed riparian habitats. In their study, agriculture and urbanization were responsible for most alterations.

Dams, canals, and other means of controlling riparian waters afford man flood protection. In order for these structures to be constructed, riparian vegetation must, in most cases, be removed from the streambanks. With regard to urbanization, this activity is a non-point source of pollution of many streams. A case study in a Colorado mountain home development (Gary et al. 1981) demonstrated high background levels of nitrate pollution in the ground water upstream, which posed minor human health problems. This contamination

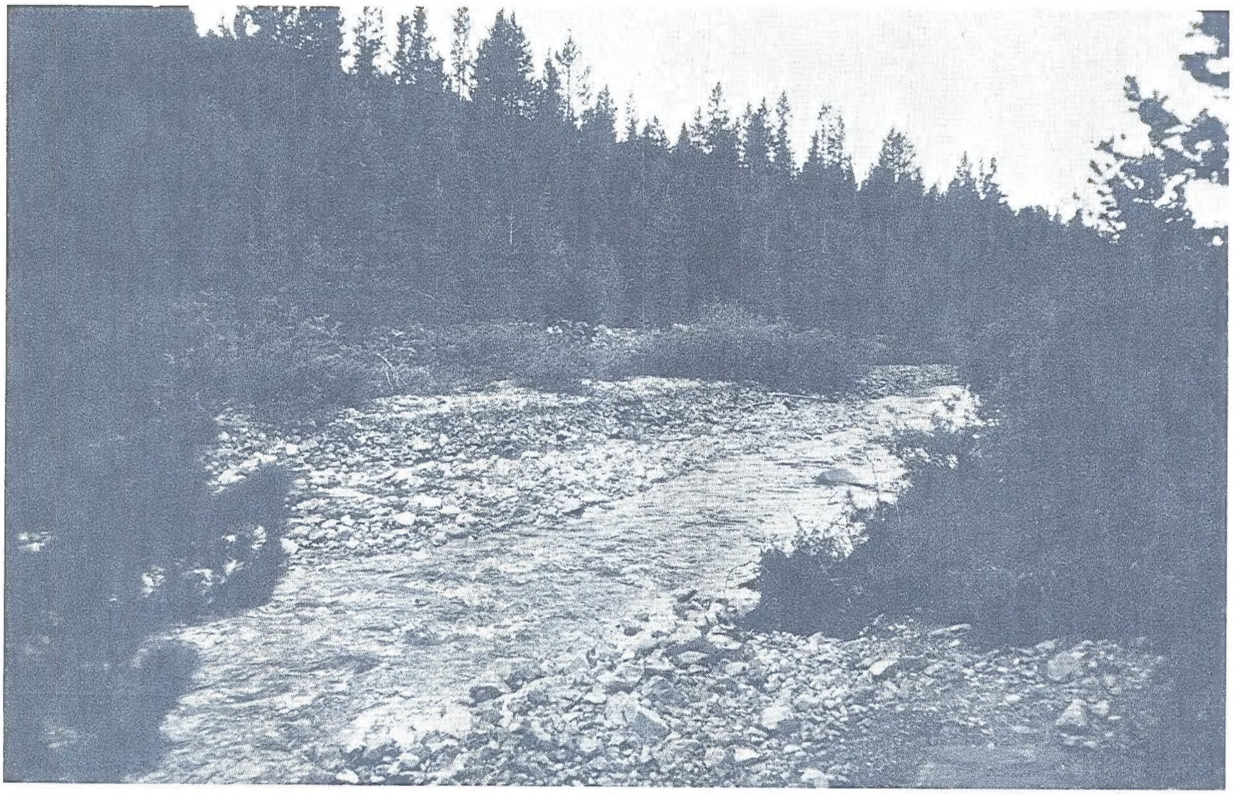


Figure 9. Channel clearance and dredging can reduce fish populations and riparian streamside vegetation.

level apparently prevented detection of additional amounts of these pollutants downstream. The study recommended that septic systems near live stream channels be phased out. This implies the waste treatment systems were not totally effective.

Rangeland riparian ecosystems are also not immune to man's cultural practices. Controlling sagebrush and other undesirable plant species often involves the use of herbicides, burning, or mechanical means. While all of these treatments may not be totally beneficial to the range resource, they may have a deleterious effect on riparian and aquatic habitat when carried out near streams. As in mitigation of logging impacts, riparian buffer zones left between the stream and rangeland will reduce the impact of these treatments on aquatic life.

Mining and its products may potentially be one of the most deleterious man-induced effects on riparian habitat. Minerals, oil, and natural gas are an integral part of our natural resources and will continue to be relied upon as short-term energy sources. The following mine-related watershed problems are listed by McArdle (1960): 1. destruction or damage to plant cover; (2) creation of erosion hazards such as access roads and drill pads; (3) sediment contributions to streams from strip pit spoil banks and placers; (4) waste discharge of acid, oil, or salt water into streams, rivers or lakes; and (5) destruction or long postponement of soil productivity by strip-mining operations. In addition, coal strip-mine operations in the Western United States may affect surface and ground-water flow in an adjacent area by aquifer disturbance resulting from the mining operation.

Stripping of flood-plain and/or woody draw vegetation may occur in mining operations. Because of the inherent mesic nature of the vegetation, a general reclamation plan for the area would be inadequate for these specialized areas. Rehabilitation of these riparian habitats will be discussed in a future section. But, in essence, the area must be recontoured so that water may flow through the drainages and the overburden material should be replaced so that capillary rise is possible and riparian vegetation can once again inhabit the area.

Water quality on a mine site is affected primarily by streamwater acidity associated with mine drainage. Potential damages to the riparian environment are the elimination of sensitive species and proliferation of more tolerant species. Reclamation of these areas would be difficult, but not impossible. Observation of hard rock and coal mine drainages and settling ponds by members of the Reclamation Research Unit and Montana State University has confirmed the existence of vegetation, chiefly grasses, growing on drastically disturbed sites affected by streamwater acidity or alkalinity, but little vegetation grows directly on the tailings (Fig. 10). Cox and Hutchinson (1980) confirmed the existence of a multielement tolerant grass species near a nickel/copper smelting complex. Seed from these and other metal-tolerant species can be used for riparian revegetation efforts.

Wildlife

Wildlife are major users of riparian habitats. Their specialized systems provide water, food, and cover for both game and non-game species. In addition, various species of fish are found in most riparian streams. The existence of wildlife in riparian zones depends primarily upon the management practices and vegetative status within the adjacent terrestrial system.

Fish

Previous discussions have described how riparian vegetation contributes to stream productivity through input of detrital material. This detritus contributes to the organic food chain, which eventually terminates with the fish themselves as primary stream predators. Another direct influence of riparian systems on fish habitat is the creation of pools and cover from logs and debris jams. Indirect factors of riparian vegetation on fish habitat include water temperature, sedimentation, and cover--i.e., streambank stabilization, influences which have been discussed in previous sections.

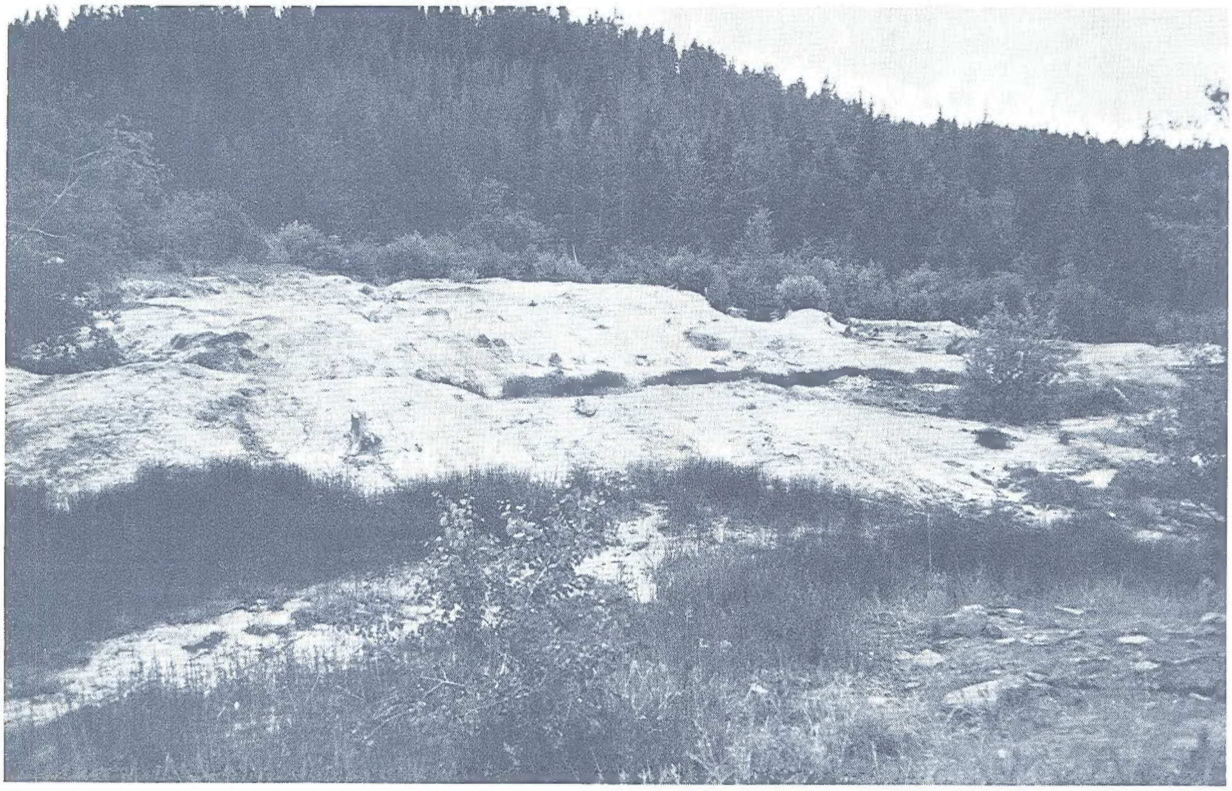


Figure 10. Biologically adapted riparian vegetation can stabilize drainages within abandoned mine tailings.

Small Mammals

Habitat disturbances such as stream channel realignment (Possardt and Dodge 1978), clear-cutting (Kirkland 1977)'fire (Krefting and Ahlgren (1974), and strip mining (DeCapita and Bookhout 1975) can alter riparian small mammal populations and community composition. Regardless of the nature of the disturbance, resident small mammal populations will be adversely affected. An example would be vegetation colonizing an area after a disturbance. In this case, vegetation and small mammals may be present after the disturbance, but the species composition would not be the same as prior to the disturbance. Geier and Best (1980) studied the effects of grazing, timber removal, and stream channel realignment on small mammal species composition and abundance.

These alterations resulted in open vegetative communities dominated by herbaceous vegetation. They found that small mammal species diversity was highest in channelized and heavily grazed upland habitats. Herbaceous vegetation dominated these sites. Other less disturbed sites contained more trees, shrubs, and forbs. Riparian areas, with more herbaceous cover, supported larger and more diverse populations of small mammals than other areas with less herbaceous vegetation.

Birds

Riparian habitats wupport a diverse population of birds, contributing significantly to the vertical diversity and zonation of these ecosystems. Harvey and Weaver (1979) found an abundance of game and non-game birds and raptors residing in the area within and immediately surrounding riparian habitats. Anderson and Ohmart (1977) found that correlations between bird population parameters and vegetational structural characteristics varied seasonally. The habitat breadth of various species was greater in summer than winter.

Where migrating birds inhabit riparian areas, narrower habitat breadths are accompanied by reduced habitat overlap among species in winter. Resident populations in riparian areas increase substantially during the winter and bird populations may be 10 times greater here than in adjacent nonriparian zones (Stevens *et al*. 1977).

Bird populations are a major component of riparian ecosystems and, because of their unique habitat requirements, are subject to effects of habitat disturbance. Stauffer and Best (1980) found that flood plains supported higher densities of breeding birds than upland woodland or herbaceous habitat. They stated that the result of a disturbance would be an alteration of desirable habitat for most species. Vertical stratification would be reduced and bird diversity would accordingly be reduced with habitat diversity. Ohmart *et al*. (1977) supported these conclusions with results from the Colorado River. As more riparian habitat was disturbed, there was a substantial reduction in species associated with this unique vegetation type.

Waterfowl populations in drainages and coulees of Montana and North Dakota can be significant. Ducks often utilize these areas for breeding grounds, but these remote riparian areas are subject to disturbance from cattle grazing. Gjersing (1975) investigated an area in north-central Montana and found that areas excluded from cattle grazing the previous year produced more breeding pairs than grazed areas. Moreover, cattle grazing during summer and fall resulted in a decrease of broods the following spring.

Big Game

Big game species most commonly associated with riparian habitat are white-tailed deer, mule deer, moose, and elk. The reason for this is their food preference and protective cover. Summer use of riparian woody draw vegetation by mule deer was extensive (Mackie 1970). Highly productive wet meadows have been cited as valuable habitat for deer and elk (Tig. 11). High quality and quantity of forage were reasons for high use of riparian wet meadows (Patton and Judd 1970). Deer and elk were observed feeding in meadows, but they did not loiter in the area. The adjacent forest was utilized for cover and animals subsequently spent more time in this area. White-tailed deer were primarily found in flood plains and riparian coulees by Allen (1968). Western snowberry was cited as the most important desirable food type of this big game species. Weedy species became more important in the diet as range conditions deteriorated. Dorn (1970) observed food habits of moose in southwestern Montana and found that willows comprised at least 84 percent of the year-round diet (Fig. 12). Diet overlap with cattle was nearly nonexistent within this reparian area and this species.

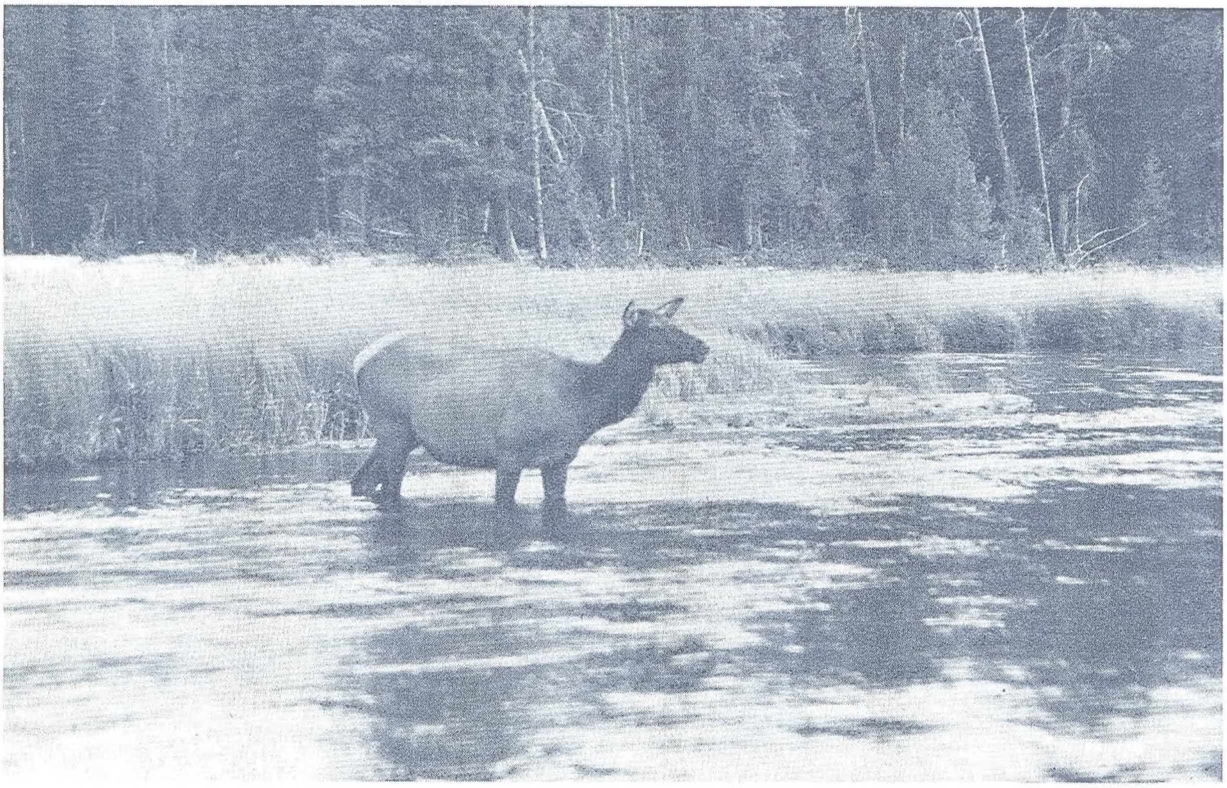


Figure 11. Elk are often found grazing riparian wet meadow vegetation.

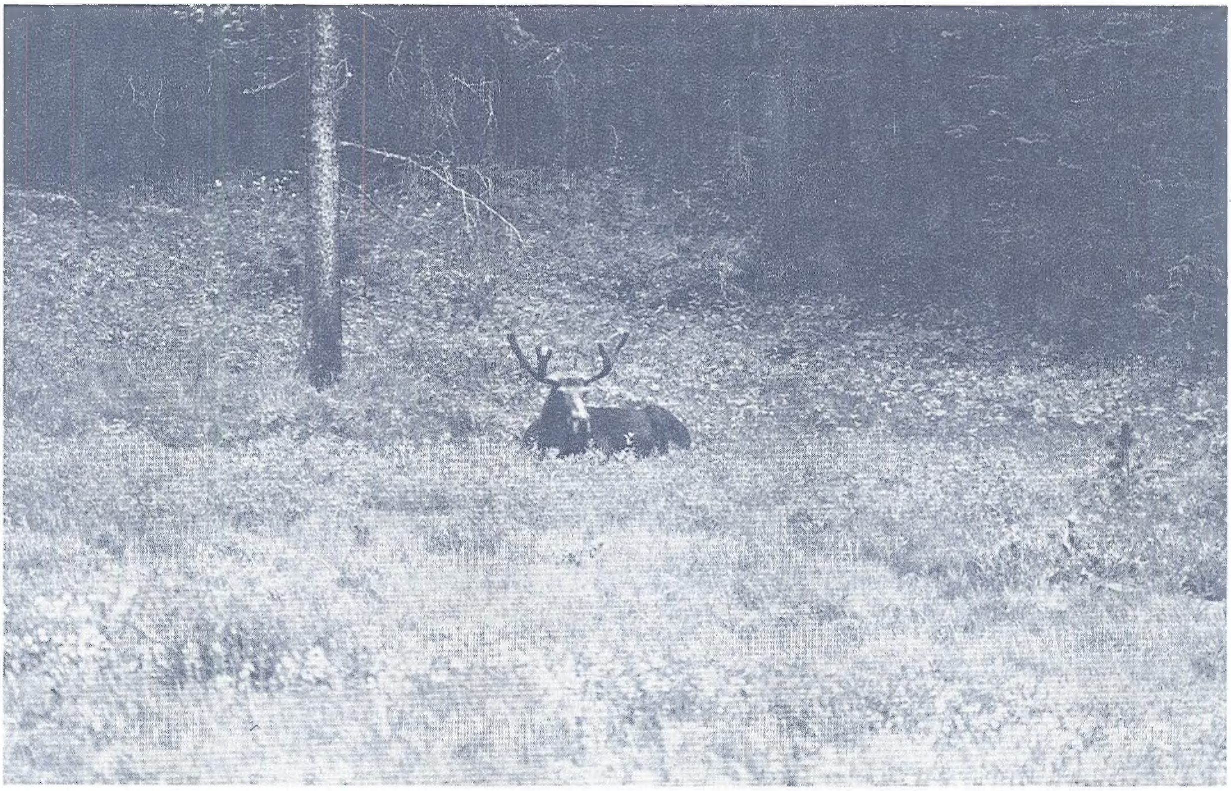


Figure 12. Riparian vegetation provides many habitat requirements of moose.

Riparian habitats offer some combination of food, cover, and water to many different species. These sites are particularly attractive because of the dramatic contrast of the plant complex with the surrounding upland community. Edge development and linear zonation are maximal in these habitats, which offers a diversity of habitat within a narrow ecological strip. For example, riparian zones dominated by deciduous vegetation provide one type of habitat in the summer when in full leaf and another type of habitat during the winter following leaf fall (Anderson and Ohmart 1977). The diversity of species is encouraged vertically as well as horizontally. Riparian zone microclimates may be attractive to various wildlife species, as wind movement is usually lower in woody areas, they are shaded, and often riparian areas are more humid.

Livestock

Streamside vegetation is most affected by grazing because riparian-aquatic zones are usually more heavily grazed than are upland terrestrial zones. In areas of high rainfall with a good distribution of water and forage this may not be a problem, but as Behnke (1979) and Behnke and Raleigh (1978) explained, it is the arid and semiarid Western regions that are particularly susceptible to destruction of riparian vegetation. Livestock tend to concentrate in streambed areas in dry months. The riparian problem is further complicated because today's range management guidelines do not call for separate management strategies for riparian areas. Often riparian environments are lumped into broad terrestrial environments for classification purposes. A logical progression leading to riparian destabilization includes long- and short-term vegetation compositional changes, streambank trampling and soil damage, stream channel degradation, alteration of water quality, and unhealthy fish habitat.

A controversial source of non-point pollution is that of livestock waste. Walter and Bottman (1967) found higher standard plate counts as well as coliform and enterococcic counts in water samples taken from a watershed closed to human traffic near Bozeman, Montana. Water from these sites used for human consumption may be harmful. A nearby watershed heavily utilized for recreation did not exhibit high bacterial cocci counts. Bacterial contmination also occurred in water samples on grazed versus ungrazed pastures in Colorado (Johnson et al, 1978).

Most literature dealing with livestock grazing on riparian habitats has documented the destructive aspects of livestock grazing. Kennedy (1977) stated that after many years of grazing the old riparia trees die, and seedlings are eaten and killed until only the most "grazing resistant" unpalatable grasses and/or trees exist. Type conversions at higher altitudes eliminate alders and willows and leave only associated grasses and grasslike plants. On semiarid river banks, cottonwoods and willows are disappearing (Severson and Boldt 1978, Crouch 1979). Marcuson (1977) reported ungrazed stream sections had 82 percent more cover per hectare than grazed sections. Overgrazing and subsequent stream course alteration had essentially eliminated tall and low shrub strata. Winegar (1977) reported a reduction in stabilizing streambank vegetation with heavy grazing. The result of this overuse is accelerated erosion in the flood plain.

In wet soils, trampling damage can be substantial to streambank stability and ripariain soils (Fig. 13). Anderson (1974) indicated that trampling displacement is evidence that surface soil has been moved downslope, exposing the soil to subsequent downward movement by water and gravity. Moreover, trampling can lead to increases in soil compaction, which reduces infiltration and increases runoff. Increases in runoff may also lower wet meadow water tables which in turn allow non-riparian species to inhabit the area. Lusby (1970) studied the long-term effects of livestock grazing on soil stability near Grand Junction, Colorado. After 10 years, grazed areas demonstrated increases in amounts of base soil and rock, while ungrazed riparian areas remained essentially unchanged. Runoff in ungrazed watersheds had been 30 percent less than in grazed watersheds, and sediment yield about 45 percent less.

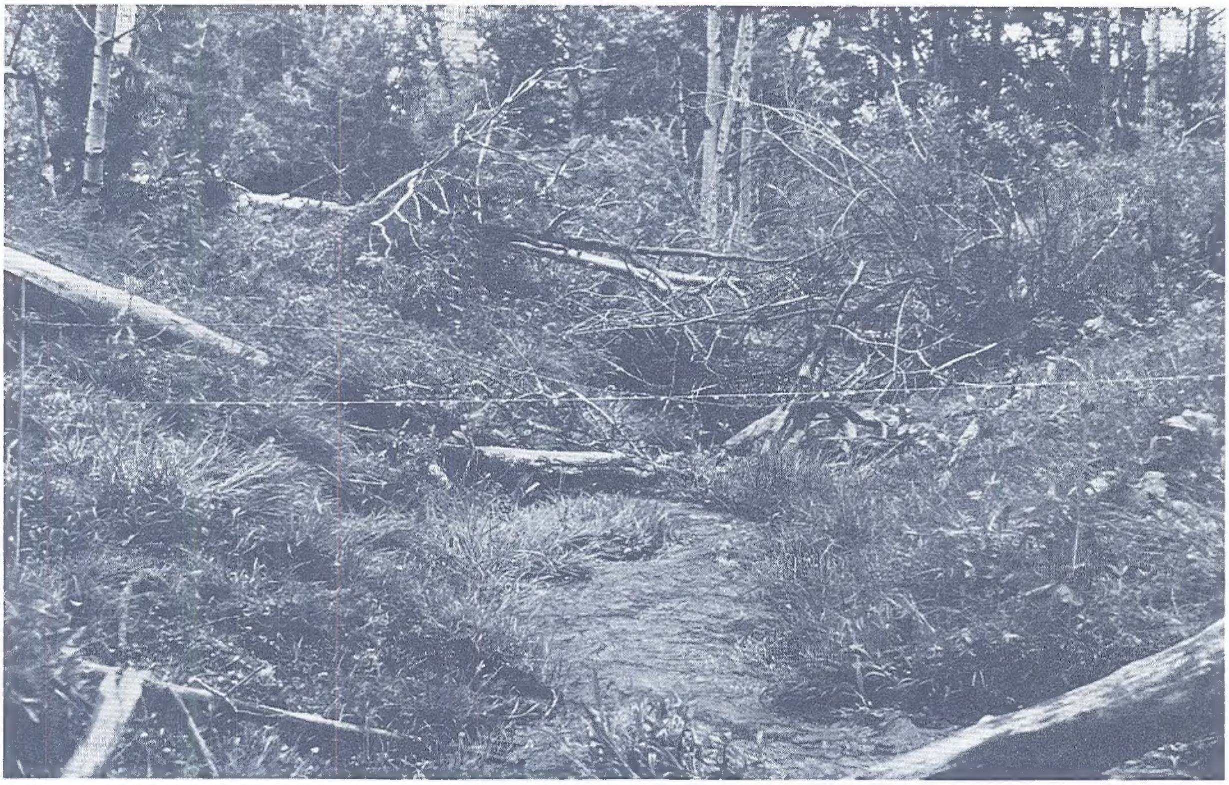


Figure 13. Trampling damage by domestic livestock (lower left corner) can lead to streambank degradation.

As livestock become more concentrated in riparian areas, less dramatic influences such as the gradual alteration of stream channel depth and width become noticeable. Overgrazing and the resultant loss of streambank vegetation create high peak stormflows. Platts (1981) found that high-intensity sheep grazing in mountain meadows created stream sections almost five times as wide and only one-fifth as deep as adjoining stream sections with only light grazing. Earlier, Platts (1979) discussed the hazards of stream channel degradation on fish populations.

Wildlife and fisheries biologists are particularly concerned about cattle grazing because of the potentially destructive effects on riparian ecosystems. Ames (1977) felt cattle have no place on riparian habitats because of conflicts with wildlife. Many other authors feel that livestock grazing is uncontrolled in riparian habitats and the result is a degradation of desirable fish habitat. The number of authors documenting either reduced numbers or reduced size of trout in grazed versus ungrazed areas was significant. For example, Marcuson (1977) reported biomass of brown trout was 3.4 times greater on ungrazed stream sections than on grazed stream sections. Moreover, biomass of fish in the ungrazed area was 87 percent greater than the biomass of fish in the grazed stream section. Similar results have been obtained from Platts (1978), Gunderson (1968), and Meehan and Platts (1978). Nearly without exception, the recommendation for reducing this problem was withdrawing the area from grazing via fencing.

MITIGATION AND REHABILITATION

Livestock

The fencing approach to rehabilitation of overgrazed areas has been advocated by many authors. Boldt et al. (1978) called cattle damage the most conspicuous of several impacts threatening the woody riparian vegetation of the Northern Great Plains (Fig. 14). They recommended fencing, partial

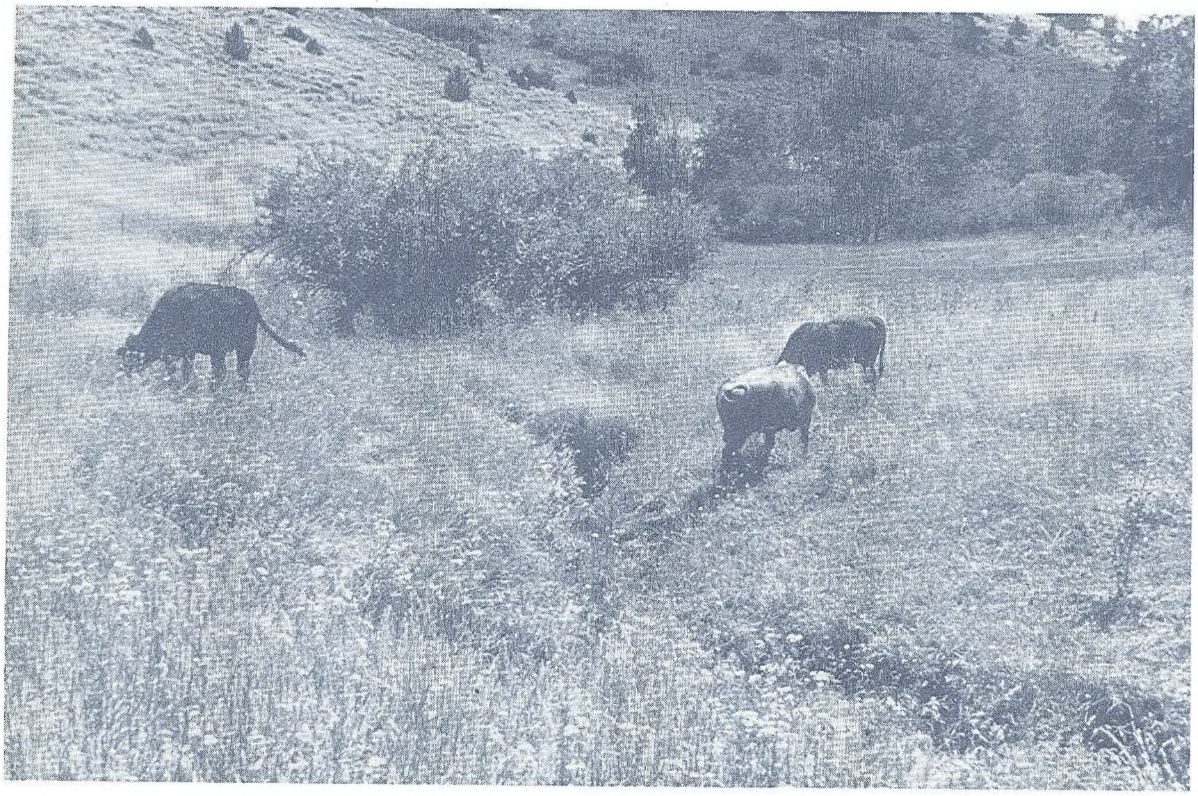


Figure 14. Cattle often graze subirrigated riparian vegetation in preference to adjacent areas.

cutting of trees, and underplanting as rehabilitation methods. Winegar (1977), Crouch (1977), Van Velson (1979) improved riparian habitat after removal of livestock grazing. Swan (1979), as a representative of cattlemen, rejected fencing as a practical mitigation solution. Busby (1979), however, advocated multiple use of riparian areas. He reasoned that livestock impact would be lessened if these areas were correctly stocked at the proper season and animal distribution controlled through use of grazing systems and conservative fencing. Kish (1981) stated that the ideal grazing strategy for riparian areas would allow maximal livestock use and still maintain other riparian resource values. He found that rest-rotation grazing systems had produced desirable results after 1 to 5 years of rest from grazing. David (1977) suggested that specialized grazing systems not be implemented until reestablishment of the vegetation had occurred. He listed several environmental and social consequences of managing the riparian habitat for domestic livestock. These consequences included: (1) a significant reduction in stocking rates, which would temporarily have an adverse economic impact on some livestock operators; (2) a decreased flooding potential; (3) a retention of long-term site productivity; (4) significant improvements in water quality due to reduced erosion and sedimentation; (5) improved forage production for domestic livestock; and (6) enhanced aesthetics and recreational opportunities.

The BLM (1978), too, has recognized that there are "...significant potentials for adverse water quality impacts from many facets of grazing activities." The BLM further states that the most significant hazards to water quality involve erosion and sedimentation. The agency also realizes the potential of pathogens and salts in decreasing water quality and seeks to mitigate the impacts of livestock grazing by reducing animal concentrations in the area. Because overgrazing is a primary cause of the degradation of water quality, BLM's first response is to "...adjust the stocking rate; then apply management for range rest" (BLM 1978). These ideas appear to follow those of David (1977). Therefore, BLM has begun a policy of implementing Best Protection Techniques (BPT) based on grazing management which would minimize water quality impacts from grazing and rangeland improvement practices.

Mining

Because of the size and intensity of disturbance, mining in the Northern Great Plains more drastically disturbs riparian vegetation than any other use. The impact can be direct, such as total elimination of a coulee or ephemeral streambed. An example of an indirect effect would be alteration of a water table and the associated vegetation in an area adjacent to the mining activity. Final regulations of the Surface Mining Control and Reclamation Act provide that mine operators must utilize the Best Technology Currently Available (BTCA) in all phases of surface mining and reclamation, regardless of the proposed post-mining use (Tyus and Lockhart 1979). The BTCA is often a subject of controversy among mine operators and reclamation specialists. Often it is the best technology which is currently available and economically prudent that is ultimately implemented. The BLM (1978) has put into effect

BPT's on severely disturbed rangelands with the goal of reducing sediment loads into nearby streams. The agency recommended a "70% plant cover for adequate hydrologic response" after an area had been reseeded. Mine operators can approach management of riparian habitats in one of two ways: mitigation of impact prior to mining or rehabilitation during postmining reclamation.

Riparian habitats can be temporarily destroyed by mining activities; therefore, the mitigation process seeks to alleviate or avoid the impact prior to habitat loss. Mitigation is a relatively new concept, and some symposia have recently been dedicated to review of mitigation techniques, primarily for reducing impacts on wildlife. Studies regarding impact of mining on upland game birds (Eng et al. 1979, Tate et al. 1979), raptors (Tyus and Lockhart 1979), or big game (Stubbs and Markham 1979) are site specific and do not directly concern riparian habitat. Studies regarding mitigation of impact on riparian habitat are almost nonexistent. The reason for this is that most riparian areas include alluvial valley floors (Fig. 15) and, to date, alluvial valley floors have not been mined. The Montana Department of State

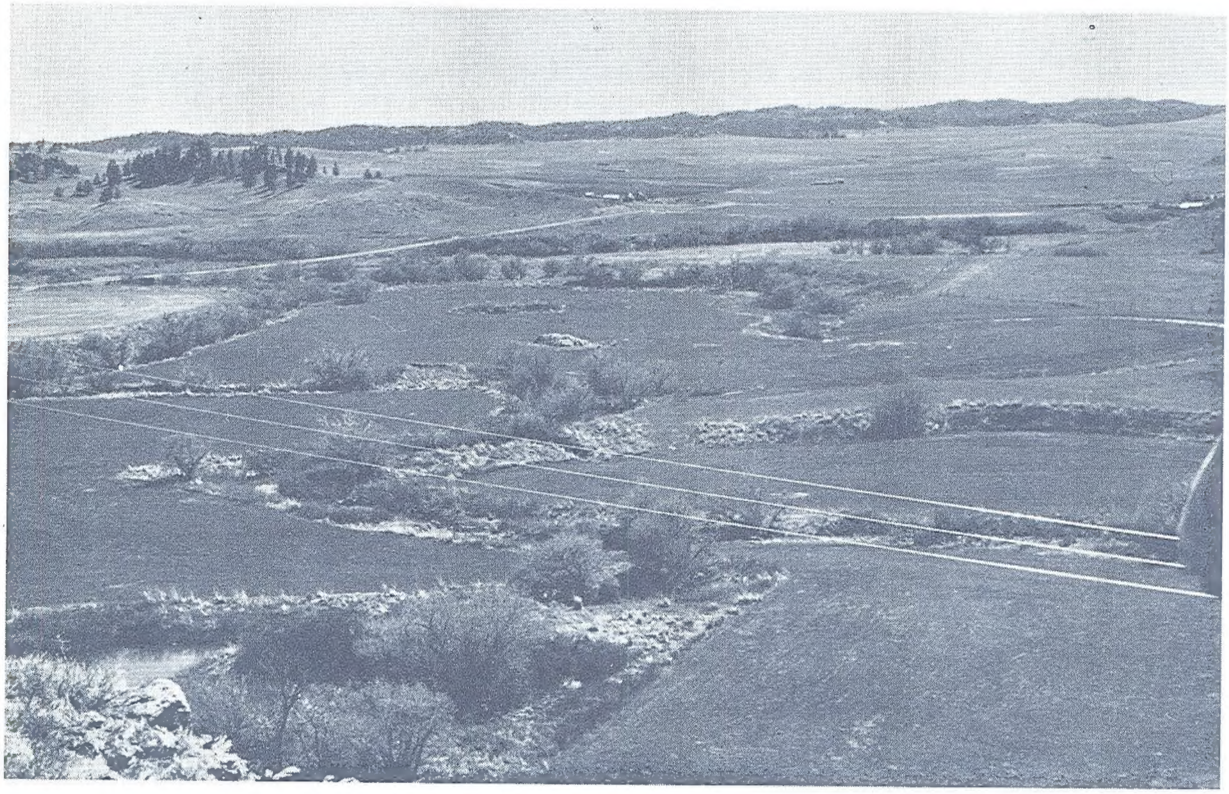


Figure 15. Alluvial valley floors contribute significantly to the agricultural economy of the local area.

Lands and other agencies in surrounding States (Department of Environmental Quality in Wyoming) have stated that alluvial valley floors cannot be mined unless the original hydrologic and vegetative properties can be restored. Alluvial valley floor reconstruction is still an unsolved problem. The woody draw vegetation is generally not considered an alluvial valley floor because it does not significantly contribute to the agricultural production of the area. These areas are primarily wildlife habitat.

The typical woody draw comprises a small portion of the land area of the Northern Great Plains but can be significant for wildlife production (Fig. 16) Wooded waterways are concentrated sources of food, shelter, and water and contribute significantly to diversity of habitat necessary for stable bird and mammal populations. Orr (1977) cited two reasons for the difficulty of reestablishing woody draw vegetation--they include moisture and suitability and stability of replaced soil. Precipitation on the Northern Great Plains is

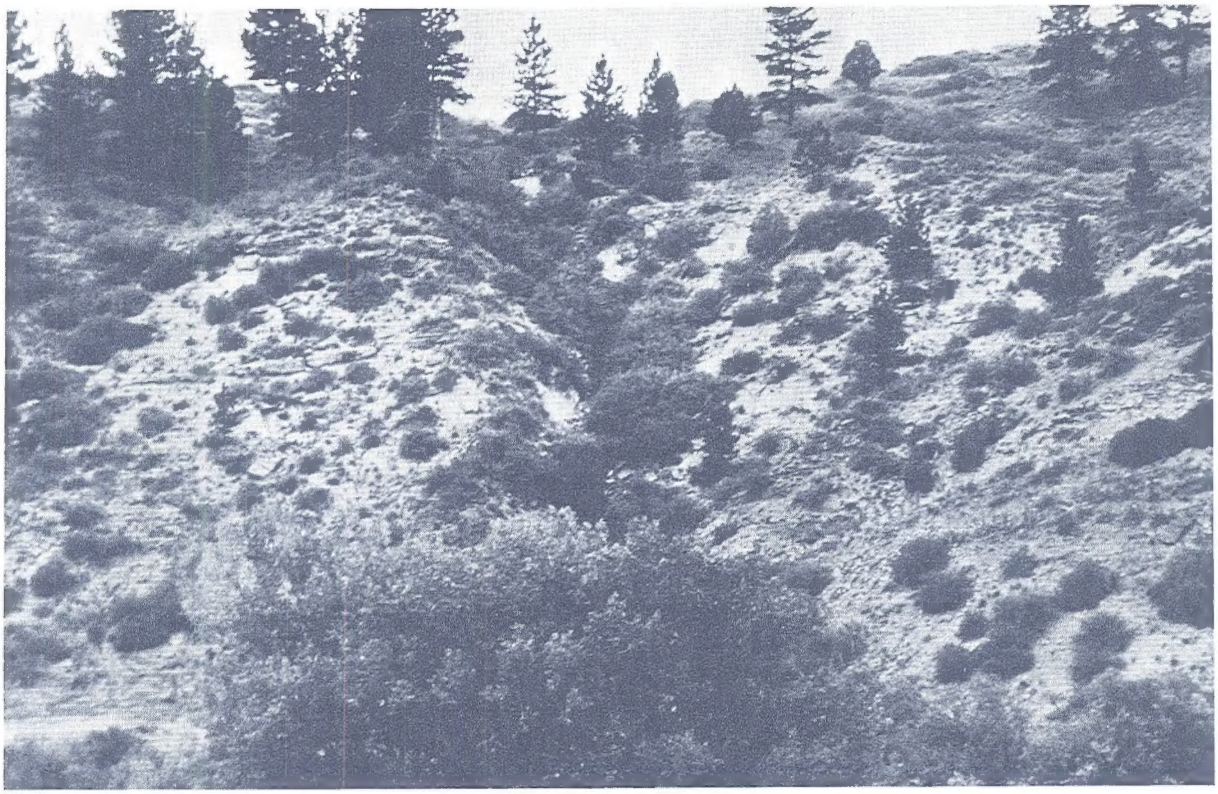


Figure 16. Woody draws and coulees increase species diversity for wildlife in the Northern Great Plains.

seasonal and often unreliable. Because of the premining water requirements of the vegetation, it is likely that woody species under dryland conditions could become established only during average to above-average precipitation years. This average figure is sometimes misleading, because if rainfall does not occur during the proper time for normal plant growth, then plants would probably not survive.

If potentially phytotoxic materials within the rooting zone can be identified, they should be placed below that zone. Soil structure and development are nonexistent after mining, and handling of this soil affects water and wind stability. A stable topsoil should be utilized as a plant-growth medium, preferably one that has not been stored for a long period of time and that still contains viable native seed and rhizomatous root stock. Careful selection of species, in addition to optimum timing and planting techniques, will assure revegetation of woody draws. Root pads, bare root stock, or containerized tubelings have been applied with success in the past.

The riparian flood plain has also been successfully revegetated. Anderson et al. (1978) discovered that the horizontal and vertical vegetation diversity and presence of cottonwoods and willows were directly correlated to the number of wildlife species in the area. After disturbance the area was reclaimed with native vegetation. Wildlife populations significantly increased in numbers and diversity 5 years after planting.

The prairie pothole region of North Dakota has been previously cited in this paper as a unique riparian type. It evolved over thousands of years of alternate wet and dry periods. Complexes of wetlands have more value to wildlife, especially waterfowl, than monotypic deep marshes. This unique habitat is being threatened by mining and irrigation. Reclamation research for reclaiming these types of areas is severely lacking. Potential for reclamation should be good if areas are restored to their original contours and if the hydrologic regime can be restored. Mitigation of irrigation has been mainly a channelization effort to divert streams away from the irrigation flood plains. If many flood plains are created, artificially high water tables and changing water quality are likely to result in loss of habitat for both wildlife and plant species.

Occasionally, diverted rivers are managed so as to reconstruct the original streambed. An essential part of streambed reclamation is the establishment of stream micro- and macroinvertebrates for developing future fish populations. In one instance, a portion of the Tongue River flowing through north-central Wyoming had been diverted so that the original stream could be stripped for coal recovery. The river was returned to its original bed after mining and recontouring. Streambed reconstruction and revegetation of streambanks with native riparian vegetation followed (Gore and Johnson 1979). Appropriate boulders, riprap, and snags were also installed to provide streambank stabilization and habitat for invertebrates and fish. Because these necessary reconstruction precautions were taken, benthic organisms were present in densities comparable to undisturbed areas 70 days after channel opening. The first fish populations were observed soon thereafter.

As strip mine operations cease in a permit area, the final cut may be left to fill with water from an interrupted aquifer, natural precipitation, and/or runoff from surrounding overburden. At present in the Northern Great Plains, the creation of any permanent water impoundment resulting from strip-mine activity must be approved by State regulatory agencies. These sites could be recontoured to allow riparian and wetland vegetation to stabilize the sol surface and provide habitat for waterfowl and stocked fish. Impoundment water quality and quantity have shown no degradation over a 3-year period (Goering and Dollhopf 1980). Thus these areas could be used as stock ponds.

Certain considerations must be given to establishing strip-mine ponds. First, it is not certain what type of vegetation would grow in an area subject to water table fluctuation. Second, the water chemistry of strip-mine ponds is directly correlated to the chemistry of the surrounding overburden. Hawkes (1978) reported that major cations within strip-mine ponds were sodium and magnesium, with lesser concentrations of calcium and potassium. The expression of wetland vegetation development is directly related to the chemical composition of pond water (Olson 1981). Another consideration in vegetation establishment around strip-mine ponds is dissolved oxygen concentration. This is highly important in the respiratory process of shallowly submerged emergents. Hawkes (1978) reported nearly optimum dissolved oxygen concentrations on strip-mine ponds due to wind action on water. Water color, clarity, and turbidity can also affect vegetation establishment near and within these ponds. Steep basin slopes also influence vegetative establishment at strip-mine ponds. The steep slopes act as an ecological confinement to species diversity. On natural ponds the slopes are usually gentle, thus allowing vegetation stratification. Steep final cut clopes compress ecotones and niches and probably do not allow gradual vegetative expression from hydric to mesic environments.

Establishing riparian vegetation on strip-mine ponds is a feasible goal. The pond edge could be regraded and plants grown which are tolerant of the diluted chemical composition of nearby runoff material. Over time, vegetation on the spoil bank should alter the chemical composition of the overburden so that runoff materials are more conducive to initiating succession on the pond banks.

A riparian watershed, flood plain, or woody draw can be rehabilitated, but with much more difficulty than reclamation of upland vegetation. Reclaiming upland communities is simpler for two reasons. First, the area is extensive and potentially a grassland community, whereas the typical riparian habitat contains an appreciable amount of shrubs. Grassland communities are easier to establish because of higher growth rates; riparian deciduous shrubs are usually found in higher ranked seral stages. It is more difficult to establish a plant community in a high than a low seral stage. Second, grassland communities and their associated vegetation have a certain amount of drought tolerance. Water is the limiting factor to plant growth in the Northern Great Plains and semiarid regions of Colorado. Riparian vegetation is adapted from mesic to hydric environments. It is primarily this factor which most restricts revegetation of riparian habitats after a severe perturbation. Water supply may not be a factor near strip-mine ponds but the chemistry of pond water may limit potentially diverse plant growth.

Reestablishing riparian vegetation is also a function of site suitability and plant adaptability. These are classic principles of rangeland renovation and improvement but are particularly applicable in riparian habitat. Some sites have the potential to be fully rehabilitated with regard to productivity and species diversity. These sites can be identified in the premining inventory as suitable sites for reclamation without special handling procedures. Other sites, such as the saline/alkaline lowlands, may contain undesirable soil characteristics which merit special handling, such as burying of the saline and/or sodic materials. Some plants are adapted for growth within this saline environment. Replacing this vegetation with more productive species would depend on replacing these soils with more desirable material.

Riparian sites also differ from adjacent upland areas because of soil differences. This is also a problem to consider when reclaiming a riparian habitat. The essential technique yet to be developed is defining where the riparian habitat begins and uplands end. If riparian habitats can be defined, soils and vegetation of the area can be delineated so that special handling techniques can be developed. As previously mentioned, water is the limiting factor for plant growth in the Northern Great Plains. Riparian revegetation efforts then must not only be concerned with plant establishment, but the establishment of a hydrologic system which will support this vegetative type. This is the major restriction to mining many riparian areas. A major research effort needs to be made in defining the extent of riparian zones and the hydrologic regime in which they exist. This would include not only a hydrologic and vegetative study, but also a soil study to identify such soil physical parameters as textural differences, which affect capillary action in the soil/water profile. Thus, the success of riparian rehabilitation/reestablishment depends on the reconstructed hydrologic balance.

GOVERNMENT MANAGEMENT POLICY

It should now be evident that riparian zones are unique ecosystems which suport a number of uses. Moreover, these systems are fragile, and overuse can quickly become abuse. Presently, several Federal agencies either indirectly or directly manage these areas. These agencies are primarily the Environmental Protection Agency, U.S. Forest Service, U.S. Fish and Wildlife Service, the Soil Conservation Service, and the Bureau of Land Management. The following paragraphs will focus on Federal policies which affect riparian habaitats.

Environmental Protection Agency

The Environmental Protection Agency's (EPA) chief interest in wetlands, including riparian systems, lies with its concern for water use, criteria regarding pollutants, and water-related resources (Davis 1978). The Federal Water Pollution Control Act (FWPCA) amendments of 1972 provided EPA with strong directives for control of water polution in the United States. EPA is the national arbiter of the environmental effects resulting from the discharge of dredged or fill materials into the waters of the United States (Davis 1978). Of primary concern is that hydrologic modification may result in the alteration of the natural capacity of a water body to cleanse itself of pollution and to support a healthy biological system. Sections 208 (Planning and Best Management Practices) and 404 (Dredge and Fill) of the FWPCA specifically address the control of hydrologic modification.

The 1972 amendments to FWPCA assigned to the U.S. Army Corps of Engineers the responsibility for administering the Section 404 permit program; EPA was given environmental jurisdiction. This section authorized the Corps of Engineers to regulate, via the permit process, discharges of dredged and fill materials which are a principal source of hydrologic modification. The 1977 amendments, known as the Clean Water Act, gave some authority to the States to operate best management practices controlling dredge and fill activities. The EPA feels that much of this regulatory role should be delegated to the States, but only for non-navigable waters and adjacent wetlands, which includes traditional riparian habitats in the Western United States. The official EPA Wetlands Policy is to "preserve the wetland ecosystems and protect them from destruction through waste water or non-point source discharges by treatment or control, or the development and construction of waste water treatment facilities, or by other physical, chemical or biological means" (Davis 1978).

U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service's (USFWS) Section 208 of the 1977 Clean Water Act seeks to control nonpoint sources of pollution and is partially administered by the same agency. The USFWS is committed to implementing Best Management Practices under Section 208, which will incorporate the maintenance of riparian vegetation and natural stream morphology (Hirsch and Segelquist 1978). The USFWS feels that these practices will not only preserve and enhance fish and wildlife resources but will also reduce soil erosion and improve water quality. The management practices control nonpoint sources of pollution. The goals of the USFWS enforcement of Section 208 are to incorporate those soil and water conservation measures that help to keep water where it falls, restrict soil erosion, and keep sediment and chemical pollutants out of the stream (Hirsch and Segelquist 1978).

While these goals are realistic, their objectives do not agree with all affected parties. Langley (1979) wrote that some people regard the law as the first step toward protecting riparian habitat on private land. His concern and that of some ranchers are that the government will begin establishing buffer zones on riparian areas via fencing to control nonpoint source pollution by grazing livestock. Ranchers have some basis for this concern. The EPA (Agee 1979) stated that Section 208, in relation to water pollution control, says ranchers must control grazing activities to the extent feasible. The conflict will undoubtedly persist for some time.

The USFWS's involvement in riparian systems originated from the agency's responsibility for protection and management of migratory birds, most notably waterfowl. The Service's current role in riparian protection involves three activities: (1) land acquisition through the Migratory Bird and Land and Water Conservation Funds and (2) participation in the environmental planning and regulatory process. The principal authority for the latter activity is the Fish and Wildlife Coordination Act. Riparian systems are included under this Act because it empowers USFWS to evaluate the impact of Federally funded, permitted, or licensed water resource development projects and to recommend measures for the mitigation and/or enhancement of fish and wildlife resources in conjunction with the development project. Third, the USFWS is involved in conducting research and inventories to develop information conducive to better riparian ecosystem management.

Soil Conservation Service

The Soil Conservation Service (SCS) has a long history of helping private individuals develop sound conservation and management practices. The primary thrust of SCS is to aid in making management decisions through objective technical assistance and advice on both private and public lands. Protection of riparian areas has historically been supported by SCS. Technical assistance programs led to application of rock/riprap materials and establishment of vegetation to protect many streambanks. In addition, SCS conservation activities have encouraged fence placement by ranchers and farmers to protect streambanks and control cattle crossing. Still, Barry (1978) explained that the goal of SCS was one of individual voluntary participation.

The SCS operates four programs which affect riparian ecosystems: (1) Conservation Operations, (2) Small Watershed Protection, (3) Flood Prevention, and (4) Resource Conservation and Development. Riparian ecosystems policy is primarily administered through the Conservation Operations Program previously discussed. The Small Watershed Protection Program provides a means for dealing with soil and water conservation problems on a large scale--i.e., more involved than a private individual would solve. Essentially the program was designed to avoid drainage of wetlands in bringing new agricultural land into production. This directly affected potential stream channelization projects and led to imposition of channel guidelines which SCS and USFWS cosponsor to make sound decisions regarding riparian resource problems.

The Resource Conservation and Development Program (RC&D) and the Small Watershed Program have similar objectives, but the RC&D is much larger in scope. There are no program restraints on the type of activities that may be carried out within a RC&D area. Funded programs must, however, be consistent with SCS goals. Projects range from preventing floods to enhancing outdoor recreation.

SCS programs and their relationship to riparian habitat are consistent with the long-term goal of technical assistance and problem solving. In fact, Barry (1978) believes that a voluntary approach by SCS combined with public incentives through government assistance programs is the most productive long-term measure to assure future viable riparian ecosystems.

U.S. Forest Service

The U.S. Forest Service's (USFS) policy toward forest management has traditionally been one of multiple use. The feeling at USFS is that each component of the ecosystem has a functional niche within the Forest Service's jurisdictional regions. Chief of the Forest Service John McGuire (1978) stated that the Forest Service recognizes the importance and unique values of riparian ecosystems. Furthermore, Forest Service policy states that these lands in the National Forest System will be managed for their unique values, following the principles of multiple use and sustained yield, and of meeting stewardship responsibilities for protecting soil, water, and vegetative resources.

Forest Service policy emphasizes flexibility in management programs. It goes beyond bvasic protection and management by including statements such as "...where applicable, improve the riparian ecosystems..." and "...continue research programs on the management, ecology, and protection of riparian enrivonments for water, fish, wildlife, timber, livestock, and recreation values and uses" (McGuire 1978). Forest Service riparian management statements show that future management will encompass the requirements of Executive Order 11990 for wetlands and Executive Order 11988 for flood plains, particularly the requirements to avoid adverse impacts from activities on the riparian ecosystem.

Livestock grazing can, at times, have an adverse impact on riparian ecosystems. Forest Service policy in this regard stresses management that minimizes conflicts, optimizes compatible uses, and protects the ecosystem. This policy toward livestock grazing is in the mold of all Forest Service statements concerning multiple use. Rupp (1979) stated that livestock management is one element of a total management plan on all National Forest System lands. The Forest Service policy does not prohibit livestock grazing in riparian areas but seeks out better management to reduce conflicts in high-intensity use areas. Multiple-use management will, because of the many users involved, create some conflicts. However, the Forest Service intends to manage riparian zones to accomodate as many uses as possible with no more than temporary impacts on soil, water, and vegetation. Finally, the Forest Service manages riparian areas with full regard toward recreation, wildlife, wood, forage, and water. Riparian zones are diverse enough to produce all of these components. It is the policy of the Forest Service to manage riparian zones with full protection for the basic resources of soil, water, and vegetation.

Bureau of Land Management

The Bureau of Land Management (BLM) administrators have recently recognized the intrinsic value of riparian systems and have begun to implement policy decisions which positively influence riparian management practices. BLM has estimated there are 218,488 ha of riparian lands in the Western United States. Of this area, 83 percent is in need of management (Almand and Krohn 1978). Current land management policies are inadequate to prevent excessive livestock grazing, road construction, and other activities in riparian areas. These impacts have affected riparian water quality and quantity, flood frequency and severity, commercial and recreational fisheries, and a wide range of wildlife species.

BLM organizes its riparian policy around many legislative acts. Chief among these is the Federal Land Policy and Maqnagement Act (FLPMA) of 1976 (Lea 1979). Under the Act, Section 102(A)(2) establishes a policy of inventorying public lands and their resources, including identifying riparian habitat, its condition, and its potential. Section 102(A)(8) requires that public lands be managed so that ecological and environmental values are protected. In addition, this section allows for maintenance of certain public lands in their natural state. Section 102(A)(11) of FLPMA requires BLM to develop regulations and plans to protect areas of critical environmental concern (ACEC). The definition of ACEC is Section 103(A) does not speak directly to riparian habitats, but the description of ACEC may be interpreted to include riparian zones. Riparian zones on public lands will require special designation as ACEC's and it is my contention that riparian areas are of such vital importance to semiarid ecosystems that special management practices are necessary.

Almand and Krohn (1978) stated that other legislation which influences BLM management of riparian zones are the Fish and Wildlife Coordination Act, the Endangered Species Act, Executive Orders 11988 and 11990 dealing with protection of wetlands and flood-plain management respectively, and the 1978 National Rangelands Improvement Act. Of particular importance are the Surface Mining Control and Reclamation Act which establishes standards which may exclude surface mining on alluvial valley floors, and the National Environmental Policy Act. Lea (1979) regarded the latter as an opportunity to adjust and regulate livestock grazing, mining, and mineral development on public lands. This Act could be a valuable legislative tool for regulating use of riparian systems.

It is apparent that BLM has the legal foundation with which to implement sound management practices on riparian ecosystems on public lands. BLM's interpretation of these Acts has initiated the following policy goals regarding riparian ecosystems: (1) to avoid long- and short-term adverse impacts associated with the destruction, loss, or degradation of riparian areas; (2) to avoid the direct or indirect support of new construction in riparian areas whenever practicable; (3) to preserve and enhance the natural and beneficial values of riparian areas, which may include constraining or excluding uses causing irreparable damage; and (4) to minimize all actions causing definable adverse impacts to riparian areas.

BLM management practices already in existence will mitigate livestock grazing on public land riparian zones. Some specifics include implementation of rest-rotation and deferred rotation grazing systems, protective fencing, alternative water source development, and implementation of buffer strips to protect riparian and wetland areas from drastic disturbances such as road construction and/or mining (Lea 1979).

Policy Summary

Through Congressional legislation, government involvement in managing the various components of riparian ecosystems is relatively widespread, usually as a result of a management goal other than, but related to, the riparian zone. The EPA is concerned chiefly with water quality as it is affected by dredge and fill operations by the Army Corps of Engineers and nonpoint source pollution. The USFWS deals with land acquisition for waterfowl management and is involved in the nonpoint source pollution regulatory process. The SCS has for many years been committed to voluntary participation in soil conservation programs. By working directly with ranchers and farmers, SCS has instituted many livestock grazing mitigation activities. Through its own efforts, SCS develops herbaceous and shrubby plant materials which, when planted and established, stabilize streambanks and provide greater habitat diversity for livestock and wildlife. The USFS is legally bound to carry out a multiple use management policy on National Forest System lands. This policy obviously cannot favor management of one type of use over another but can allow the use of riparian systems without abusing these ecosystems. The impacts of livestock grazing, road construction, and mining on other uses will have to be considered before those other uses are no longer viable. The BLM is the chief land steward in the Western United States. As such, it is committed to managing all Western ecosystems. The BLM, like the Forest Service, is allowing use of riparian areas on public lands, but policy statements show the tendency toward mitigation rather than prevention of impact. The BLM and the other Federal agencies are entrusted with the preservation and conservation of riparian ecosystems. If these policies can be implemented, the public should enjoy the perpetuation of this natural resource.

SUMMARY

The riparian habitat is a small, unique habitat type found in nearly all major resource areas of the Northern Great Plains. Its distinguishing characteristic from surrounding areas is the association with water. It is an ecotone between aquatic and upland vegetation types. Vegetation on these sites serves to stabilize the soil surface and to prevent extreme runoff from entering adjacent streams. At the same time, riparian vegetation is the chief supplier of detrital material to freshwater stream macro- and microfauna. There are many users of the riparian zone, and conflicts in allocation of resources often arise. Riparian zones are particularly sensitive to disturbance and must be managed under different policies than upland grazing sites. Riparian habitats offer unique challenges to the field of reclamation because of the association with surface and/or ground-water systems. It is felt that these areas can be reclaimed, but reclamation research is needed so that the effort can be all-inclusive. That is, research cannot be restricted to only the soils or hydrology or vegetation of the area. If riparian areas are to be properly reconstructed after severe disturbances, the effort should be comprehensive.

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APPENDIX A

TABLE 1. GRASSES

Scientific Name	Common Name
Agropyron spp.	wheatgrass
A. dasystachyum	thickspike wheatgrass
A. riparium	streambank wheatgrass
A. smithii	western wheatgrass
A. spicatum	bluebunch wheatgrass
A. trachycaulum	slender wheatgrass
Agrostis alba	redtop wheatgrass
A. scabia	rough bentgrass
Andropogon gerardi	big bluestem
A. hallii	sand bluestem
Beckmania spp.	sloughgrass
Bouteloua gracilis	blue grama
Bromus inermis	smooth bromegrass
B. marginata	mountain bromegrass
B. tectorum	cheatgrass
Calamagrostis spp.	reedgrass
C. canadensis	bluejoint reedgrass
C. inexpansa	northern reedgrass
Calamovilfa longifolia	prairie sandreed
Danthonia spicata	poverty oatgrass
Deschampsia caespitosa	tufted hairgrass
Distichlis spp.	saltgrass
D. stricta	inland saltgrass
Elymus canadensis	Canada wildrye
E. cinereus	basin wildrye
E. triticoides	creeping wildrye
Glyceria elata	tall mannagrass
Hilaria jamesii	galleta
Hordeum spp.	barley
H. jubatum	foxtail barley

GRASSES (continued)

Scientific Name	Common Name
Muhlenbergia richardsonis	mat muhly
Panicum obtusum	vine-mesquite
P. virigatum	switchgrass
Phleum alpinum	alpine timothy
Poa spp.	bluegrass
P. compressa	Canada bluegrass
P. palustris	fowl bluegrass
P. pratensis	Kentucky bluegrass
P. secunda	Sandberg bluegrass
Puccinellia spp.	alkaligrass
P. airoides	Nuttall's alkaligrass
Schizachyrium scoparium	little bluestem
Scolochloa festucea	rivergrass
Setaria viridis	green bristlegrass
Sitanion hystrix	bottlebrush squirreltail
Sorghastrum nutans	indiangrass
Spartina gracilis	alkali cordgrass
S. pectinata	prairie cordgrass
Sporobolus airoides	alkali sacaton
S. cryptandrus	sand dropseed
Stipa columbiana	Columbia needlegrass
S. comata	needleandthread
S. viridula	green needlegrass

GRASSLIKE PLANTS

Scientific Name	Common Name
Carex spp.	sedge
C. atherodes	slough sedge
C. filifolia	slim sedge
C. lanuginosa	woolly sedge
C. nebraskensis	Nebraska sedge
Eleocharis spp.	spikerush
E. macrostachye	spike sedge
E. palustris	creeping spikerush
Juncus spp.	rush
J. balticus	Baltic rush
Scirpus spp.	bulrush
S. americanus	American bulrush
S. paludosus	alkali bulrush
Typha spp.	cattail

FORBS

Scientific Name	Common Name
Achillea millefolium	western yarrow
Aconitum spp.	monkshood
Agoseris glauca	pale agoseris
Allium textile	wild onion
Amaranthus graecizans	prostrate pigweed
Antennaria rosea	rose pussytoes
Apocynum cannabinum	indianhemp
Aquilegia spp.	columbine
Artermisia michauxiana	michaux sagewort
Aster spp.	aster
A. canescens	hoary tansyaster
A. vimineus	smallwhite aster
Barbarea orthoceras	American wintercress
Camelina microcarpa	littlepod falseflax
Castilleja spp.	Indian paintbrush
Centaurea maculosa	spotted knapweed
C. repens	Russian knapweed
Cerastium viscosum	sticky cerastium
Chenopodium album	lambsquarters
Circuta spp.	waterhemlock
Cirsium spp.	thistle
C. vulgare	bull thistle
Comandra umbellata	bastard toadflax
Equisetum spp.	horsetail
Erigeron spp.	fleabane
Eriogonum spp.	buckwheat
Fragaria vesca	European strawberry
Galium boreale	northern bedstraw
Geranium spp.	geranium
Geum triflorum	common geum
Grendelia squarrosa	earlycup gumweed

FORBS (continued)

Scientific Name	Common Name
Glycyrrhiza glabra	common licorice
G. lepidota	American (wild) licorice
Helianthus spp.	sunflower
Hydrophyllum spp.	waterleaf
Iris spp.	iris
Iva axillaris	poverty sumpweed
Kochia spp.	summer cypress
Lepidium densiflorum	common lepidium
Linaria vulgaris	yellow toadflax
Linum spp.	flax
Lomatium foeniculaceum	lomatium
Lupinus lepidus	pacific lupine
Lychnis alba	whitecockle campion
Melilotus spp.	clover
Mentha spp.	mint
M. arvensis	field mint
Mimulus spp.	monkeyflower
M. guttatus	common monkeyflower
Musineon divaricatum	musineon
Myosotis sylvatica	woodland forget-me-not
Opuntia polycantha	plains pricklypear
Oxytropsis spp.	locoweed
Pedicularis groenlandica	elephanthead pedicularis
Phlox spp.	phlox
Plantago major	common plantain
P. spinulosa	spindle plantain
Polygonum amphibium	ladysthumb knotweed
P. coccineum	swamp knotweed
P. erectum	erect knotweed
Potentilla spp.	cinquefoil
P. anserina	silverweed cinquefoil
Rudbeckia laciniata	cutleaf coneflower
Rumex occidentalis	western dock

FORBS (continued)

Scientific Name	Common Name
Salsola kali	Russian thistle
Silene cucubalus	bladder silene
Sium suave	hemlock waterparsnip
Solidago spp.	goldenrod
S. altissima	tall goldenrod
S. occidentalis	western goldenrod
S. nana	baby goldenrod
Sparganium eurycarpum	giant burreed
Sphaeralcea spp.	globemallow
Sphaeralcea coccinea	scarlet globemallow
Suaeda depressa	pursh seepweed
S. fruticosa	alkali seepweed
Taraxacum officinale	dandelion
Teucrium spp.	germander
Tragopogon dubius	common salsify
Trifolium dubium	small hop clover
T. repens	white clover
Triglochin palustris	marsh arrowgrass
Verbascum thapsus	flannel mullein
Veronica americana	American speedwell
Vicia americana	American vetch
Viola spp.	violet
Zanthium strumarium	cocklebur

SHRUBS

Scientific Name	Common Name
Amelanchier spp.	serviceberry
A. alnifolia	common serviceberry
Artemisia cana	silver sagebrush
A. frigida	fringed sagebrush
A. longifolia	longleaf sagebrush
A. tridentata	big sagebrush
Atriplex spp.	saltbush
A. canescens	fourwing saltbush
A. confertifolia	shadscale
Celtis occidentalis	blackberry
Ceratoides lanata	winterfat
Chrysothamnus spp.	rabbitbrush
C. nauseosus	rubber rabbitbrush
C. viscidiflorus	green rabbitbrush
Crategus spp.	hawthorn
Elaeagnus argentea	silverberry
Kalmia polifolia	bog kalmia
Lonicera caerulea	berry honeysuckle
Potentilla fruticosa	shrubby cinquefoil
Prunus americana	American plum
P. virginiana	chokecherry
Rhamnus alnifolia	alderleaf buckthorn
Ribes spp.	currant
R. hudsonianum	Hudsonian currant
Rosa spp.	rose
R. acicularis	prickly rose
R. arkansana	Arkansas rose
R. nutkana	nootka rose
R. woodsii	woods rose
Rubus spp.	raspberry
R. idaeus	red raspberry
Sambucus racemose	black elderberry
S. canadensis	American elderberry
Sarcobatus spp.	greasewood

SHRUBS (continued)

Scientific Name	Common Name
Shepherida argentea	silver buffaloberry
Symphoricarpos spp.	snowberry
S. occidentalis	western snowberry (wolfberry)

TREES

Scientific Name	Common Name
Acer negundo	boxelder
Almus incana	alder
Betula occidentalis	water birch
B. papyrifera	paper birch
Cornus stolonifera	redosier dogwood
Elaeagnus augustifolia	Russian olive
Fraxinus pennsylvanica var. *lanceolata*	green ash
Juniperus scopulorum	Rocky Mountain juniper
Pinus contorta	lodgepole pine
Pinus ponderosa	ponderosa pine
Populus sargentii	plains cottonwood
P. trichocarpa	black cottonwood
P. tremuloides	quaking aspen
Pseudotsuga menziesii	Douglas-fir
Quercus macrocarpa	bur oak
Salix spp.	willow
S. amygdaloides	peachleaf willow
S. bebbiana	Bebb willow
S. interior	sandbar willow
S. mackenziana	Mackenzie willow
S. nigra	black willow
Ulmus americana	American elm

THE ROLE OF GREENHOUSE STUDIES IN EVALUATING SOIL AND GEOLOGIC MATERIALS AS PLANT GROWTH MEDIA IN RECLAMATION

by

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INTRODUCTION

One of the needs in reclamation is to develop procedures for evaluating the ability of soils and geologic overburden to sustain vegetative growth. While some researchers feel that such procedures can only be developed under actual field conditions, field tests are costly and time consuming. Also, results are often clouded by losses due to weather, diseases, and insects. Laboratory and greenhouse studies permit closer experimental control but admittedly do not always reflect soil-plant-water relationships as they exist under actual field conditions. Perhaps a combination of approaches is necessary to meet the needs of reclamation planners.

The objective of this paper is to demonstrate how greenhouse studies and associated soil and plant diagnostic techniques can be utilized in reclamation work.

DEVELOPING DIAGNOSTIC TECHNIQUES

Development of diagnostic technique programs for interpreting soil-plant relationships entails three distinct efforts: 1) analytical or laboratory procedures; 2) research to provide correlation and calibration data; and 3) interpretations and recommendations.

The success of any diagnostic program depends on the degree to which these parts can be combined into an overall program that satisfies interpretive needs. The procedures which have been utilized in meeting the aforementioned requirements of a diagnostic technique program are laboratory methods, greenhouse studies and associated soil and plant characterization, and field studies.

Analytical soil test procedures, calibration of laboratory data, limitations of soil and plant testing, and requirements for developing interpretations have been discussed in detail by many workers. The reader is referred to the following selected articles: American Potash Institute (1948), American Society of Agronomy (1977), Baker (1973), Bates (1971), Berg (1975, 1978), Black (1965), Borlan et al. (1968), Chapman (1966, 1967), Cox and Kamprath (1972), Hanway (1967, 1971, 1973), Fried and Dean (1952), MacLean et al. (1952), Mortvedt and Terman (1978), Munson (1970), Ozus and Hanway (1966), Peck and Melsted (1973), Rouse (1967), Sandoval and Power (1978), Terman and Mortvedt (1978), Tisdale (1967), Ulrich and Hills (1967), USDA (1954), Viets and Lindsay (1973), Walsh and Beaton (1973), Welch and Wiese (1973), Baker and Chesnin (1975), Jenny (1941), and Prabhakarannair and Cottenie (1969). The work of all these researchers will not be reviewed in detail here, but their findings will be incorporated as they apply to calibration data needed for developing interpretations applicable to disturbed lands.

Conceptual Development

Acute problems face researchers with respect to assessing the suitability of soil and geologic materials for reclamation. For example, most existing soil test correlation data were developed for agronomic crops grown under soil moisture regimes quite different from those in which surface mining is taking place in the West. Berg (1978) reminds us that plant species used in revegetation of disturbed lands may be less sensitive to nutrient deficiencies or toxicities than agronomic crops. Bauer et al. (1978) state that the principal research efforts needed are to confirm the efficacy of soil and plant diagnostic techniques in current use on disturbed sites.

We have a tremendous wealth of knowledge and technical capability for addressing these problems. The questions seem to be, "How do we go about applying this knowledge and capability to the environments for which little correlation research has been done?" "Do we need new laboratory precedures?" "Are greenhouse studies useful?" "What kind and how many field experiments do we need?" etc.

Perhaps a way to focus on needs and the types of research required to meet these needs is to view a reclaimed area or areas to be reclaimed as a "dynamic system." Jenny (1941) has provided us with an excellent approach through his state factor equation, which is:

$$S = f\ (Cl,\ O,\ P.M.,\ R,\ T\ \ldots),$$

where S = Soil or soil property,
which is a function (f) of:
Cl = Climate,
O = Organisms,
P.M. = Parent material,
R = Relief,
T = Time, and
... = Perhaps other factors.

This generalized equation, although it cannot be solved easily, emphasizes the interrelationships of the factors that influence a plant-soil system and further points out that no one factor is entirely responsible for the nature of a given system in the field. The equation emphasizes that the nature of the system at any particular time is an integrated value of all the factors that influence the dynamics of the system.

Jenny's equation could be modified and written as follows to identify the factors important in evaluating the potential success of a reclamation plan: $X = f\ (S,\ Cl,\ T,\ P,\ M,\ \ldots)$. In a generalized way this equation states that X (potential suitability of soil and geologic overburden material) is a function (f) of the (S) soil or plant growth media, (Cl) climate, (T) time, (P) plant, (M) management, and perhaps other factors.

Although this equation appears to be somewhat simple, the number, kinds, and degree of interactions among the factors as they influence a system are very complex. But the equation serves as a basis for keeping in mind those factors that influence the properties of a soil-plant system and can help determine the kinds of studies most useful for revealing these relationships. For example, if one is interested in assessing the influence of soil properties on the dynamics of a soil-plant system, it is desirable to study soils with different properties. To do this, other factors would have to be held constant. Similarly, to evaluate the performance of different plant species, one would want to hold other factors constant. The equation demonstrates that each of the factors must always and everywhere be examined. The key question becomes, "Which of these factors and/or combination of factors are important for a given time and place?" This leads to the next question, "What types of experiments and/or studies are best suited for evaluating the interaction or influence of these factors for a given time and place?"

Factors That Control Soil-Plant Systems

Soil

Soil is the water source, anchorage, and source of mineral nutrients for plants. The water available to the plant, when all other factors are constant, is primarily related to the amount of available water held within the plant root zone. The nutrients available to the plant are influenced by soil pH, moisture status, overall nutrient status, and nature of the plant. Because no two species of plants growing on the same soil take up the same quantities of nutrients, soils with the same concentrations of a given nutrient may not meet the requirements of different crops. For example, sorghum may show zinc and iron deficiences on soils adequate for wheat and corn, respectively. Excess phosphorus may also induce zinc deficiencies in some plants.

Laboratory tests for evaluating plant nutrients must be correlated with crop response on a large number of soils demonstrating low to high nutrient levels. Initially, such studies are often done in the greenhouse where it is possible to compare a large number of soils with varying chemical and physical properties under controlled growing conditions. Greenhouse studies allow plant species to be grown simultaneously. Because such studies can be conducted relatively quickly, they serve as a good screening mechanism for determining which nutrients may be deficient for a particular species and also serve to evaluate plant nutrient interactions critical to individual species.

Mortvedt and Terman (1978) have pointed out some limitations of greenhouse studies: 1) the restricted root volume in greenhouse pots can accentuate plant response to applied nutrients, 2) poor light quantity and quality as well as lack of optimum amounts of some nutrients may influence plant response and yields, 3) subsoil and climatic effects cannot be readily measured, and 4) some plants cannot be successfully grown to maturity in the greenhouse. The latter is of particular importance in mined land reclamation--that is, establishing many native species in the greenhouse for assessment. However, with proper selection of groups of plant species, in conjunction with soils having different chemical or physical properties, greenhouse studies can be designed to develop basic soil-plant interactions. The results may not be directly applicable to field conditions but may be used to identify the key variables that should be considered in field studies. Follow-up field studies can then be conducted for calibration of soil and plant analysis procedures.

One of the major problems confronting reclamation planning is the "state of weathering" of geologic materials that might be used as plant growth media. Geologic materials brought to the surface and exposed to an active biogeochemical weathering process may change both chemically and physically over time. The net result may be an increase or decrease in the availability or mobility of some elements in the soil system. Increase in availability might result in toxicities to plants or to animals which forage on the plants. Greenhouse studies and associated laboratory mineralogy studies can effectively assess the nature and kinds of chemical and physical changes that might take place in geologic materials through time, but they may not be able to identify the rate at which these changes take place, the rate at which constituents mineralized from the materials may be leached or moved in the soil system, or the rate at which particular elements, particularly if they are toxic, may build up in the system. Greenhouse studies can, however, identify the potential problems that might occur. Field studies can then be designed to evaluate the long-term changes in the chemical and physical nature of these materials through time.

Climate

Climate, as a factor in controlling the dynamics of a plant-soil system, has a direct relationship to the nutrient requirements of a plant and also to water availability. During periods of favorable weather, plants can utilize more nutrients for growth than in dry periods. Similarly, in climates where productivity is high, the need for nutrients is also greater. Thus, a soil may be able to meet the water and nutrient requirements of a crop when the production is low but fail to do so when the growth rate and productivity are high. These relationships, although they can be simulated in a greenhouse, are difficult to simulate for some environments. Basic water-plant nutrient interactions can be studied in the greenhouse and then tested in the field. Field testing is difficult, however, because of the number of experiments required and the variability in existing conditions in areas of the Western United States where reclamation occurs.

Through wetting and drying and freezing and thawing cycles, greenhouse studies can be used to evaluate changes in the chemical and physical nature of materials through time. Further, they can indicate how plant growth response may change due to weathering. Again, it is difficult to simulate field conditions, but basic relationships can be established.

Time

It is well known that time, as related to stage of plant development, has an important influence on plant nutrient and water requirements. Studies to determine nutrient requirements and/or response of plants to nutrients at different stages of growth can be evaluated in greenhouse studies. These types of studies can be particularly useful if combined greenhouse and plant analyses studies are conducted to determine the time-plant nutrient-soil interactions.

Plant

Plants of different genera and even those of the same genus, as well as different varieties of a single species, may differ significantly in water requirement and nutrient uptake from a given soil. It has been shown that unequal amounts of a given nutrient absorbed by different crops from a deficient soil are related not to different nutrient requirements within the vegetative tissues, but rather to the kind and extent of root development (Ulrich and Hills 1967). There are many different types of plant-associated responses that would be difficult to study with field experimentation alone. For example, nutrient deficiencies in many crops produce no specific symptoms other than a general lack of vigor and reduced yield (Ulrich and Hills 1967). Plant analyses as part of a greenhouse study can be used to identify these types of deficiencies and thus lead to appropriate corrective measures. In addition, visible deficiency symptoms often are not a useful guide until the deficiencies are relatively acute. Combined chemical soil analyses and tissue analyses on greenhouse plants may indicate nutrient shortages that are not severe enough to produce recognizable symptoms. It is probably economically prohibitive to establish field trials to assess these types of problems.

Greenhouse studies are also useful to determine whether plant nutrients added to the soil to correct deficiencies actually enter the plant. Sometimes applied nutrients are not near enough to actively absorbing roots. When no yield response is obtained, the researcher may erroneously conclude that the nutrients were not lacking. Where there is no recognizable symptom, the researcher needs to know whether nutrient uptake was prevented either by some soil reaction or an unfavorable placement of fertilizer, or whether the nutrient was absorbed but was ineffective in correcting the deficiency. Other types of plant responses are interactions or antagonisms among plants and nutrients. This type of response often becomes more critical when geologic materials are used, due to the chemical changes in the materials upon weathering. As pointed out earlier, it is not unusual to find that the addition of some nutrients reduces uptake of certain other nutrients. Greenhouse studies can aid in the identification of problems such as this and can lead to practical solutions.

Another useful aspect of greenhouse studies is the ability to analyze whole plants or plant parts through the season to determine changes in plant nutrient composition over time.

Management

The response of plants to a particular environment is affected by management; such things as fertilization, liming, crop rotation, drainage, tillage, and irrigation all affect plant growth. The influence of management practices on soil-plant relationships is often overlooked in developing field experiments and should be considered in the design of greenhouse studies as well.

In summary, we must maintain an awareness that the aforementioned factors, as they control the chemical, physical and biological processes of a system, involve an infinite number of basic soil-plant relationships. More importantly, some of these relationships are nearly impossible to study unless they can be isolated; that is, specific relationships can be studied only if other variables are held constant. Even though the argument is valid concerning the inability of greenhouse studies to simulate field conditions, it is equally true that field conditions do not easily provide the conditions required for study of some soil-plant relationships. We must be open to the fact that each of the research approaches--laboratory, greenhouse, and field--has a role to play in developing a better understanding of soil-plant systems.

APPLICABILITY OF GREENHOUSE STUDIES TO RECLAMATION

The literature contains reports of numerous greenhouse studies dealing with soil-plant relationships, but relatively few where the principal objective was to develop interpretations directly applicable to field situations. However, several of the latter are cited here: Barnes and Friman (1964), Bowman et al. (1978), Follett and Lindsay (1971), McLeod and Bradfield (1963), Parks et al. (1967), and Zubriski (1971). These are not necessarily the most applicable or best studies, rather they represent a cross-section of the literature regarding the application of greenhouse studies in the calibration of laboratory data and plant response to field conditions.

Background

Sites for which greenhouse studies were conducted by our laboratory included:

Location	Source
Bear Creek, Montana	(Herron and Berg 1977)
Horse Nose Butte, North Dakota	(Herron and Berg 1977)
Red Rim, Wyoming	(Herron and Berg 1977)
Bisti West, New Mexico	(Herron and Berg 1977)
Foidel Creek, Colorado	(Herron and Berg 1977)
White Tail Butte, Wyoming	(Herron and Berg 1977)
Alton Coal Field, Utah	(Herron and Berg 1977)
Hanna Basin, Wyoming	(Herron and Berg 1977)
Otter Creek, Colorado	(Herron and Berg 1977)
Taylor Creek, Colorado	(Herron and Berg 1977)

Pumpkin Center, Montana	(Heil 1978)
Kimbeto, New Mexico	(Heil 1978)
Beulah Trench, North Dakota	(Heil 1978)
Fish Creek, Colorado	(Heil 1978)
Emery, Utah	(Heil and Deutsch 1979)
Lay Creek, Colorado	(Heil and Deutsch 1980b)
Prairie Dog Creek, Montana	(Heil and Deutsch 1980a)
Ojo Encino, New Mexico	(Heil and Deutsch 1980c)
Arkoma, Oklahoma	(Heil and Deutsch 1980d)
McCallum, Colorado	(Heil and Deutsch 1980e)

Studies on the first 10 sites included only yield and plant growth response data. Other sites included combinations of selected soil, chemical, and plant analyses in addition to the greenhouse growth studies. These studies involved approximately 1,500 different materials, of which roughly two-thirds were geologic materials and one-third were soil samples. About 80,000 individual observations were made, including yield, chemical and physical characteristics of soil and geologic materials, and plant anaylses.

Western wheatgrass was the principal crop grown. Other species (native) were grown on materials from one to two sites, but our success in establishing these species in pots was not good. Pot sizes varied from 1.0 to 2.0 kg of material among sites. Pot size was consistent for a given site. Field capacity of all materials was determined to serve as a basis for watering the pots on a daily basis. Nitrogen and phosphorus fertilizers were added to every pot to remove these two nutrients as variables. Two replications were used. Total plant material produced was harvested at seven to eight weeks.

For sites where plant analyses were conducted, plants were prepared for laboratory analysis using standard procedures. For some sites, soils were sampled from the pots following harvest to compare postharvest soil chemical characteristics with pre-plant. This was done to evaluate the degree of change in some soil properties due to biogeochemical weathering during the plant growth period.

Evaluation of Results

Greenhouse Yields

Initial studies involving the first 10 sites identified in the previous section concentrated on evaluating the relative suitability of soil and geologic materials on the basis of yield, the presence of shoot growth from rhizomes, the degree of soil surface cracking, the amount of salt crusting, and the average plant height (Herron and Berg 1977).

Relative yields among sites were compared based on percentage of yield of a standard soil. The standard was the Platner, which is a highly productive soil formed on wind-worked outwash materials found in eastern Colorado. In this study, relative yields below 33 percent were considered low, between 34 and 66 percent medium, and 67 percent and above high. The percentage of geologic and soil samples from the sites in each range were:

	Percent	
	Geologic	Soils
Low	26	20
Medium	52	51
High	22	29

The results of this study suggest that a large number of the geologic materials were as suitable as soil materials from the sites. These studies provided a useful screening mechanism for establishiing a relative plant response assessment among different soil and geologic materials.

In general, this study indicated that nearly all soil and geologic materials with relative yields greater than 67 percent were suitable for plant growth, and those with relative yields less than 33 percent were unsuitable, due either to chemical or physical limitations. The samples which fell in the medium category included some materials which would make favorable plant growth media, but also included materials which would be unsuitable under field conditions. For example, overburden samples with higher field capacities for water generally yielded most. In the field, under arid and semiarid conditions, these fine-textured materials would be the more droughty soils because of greater surface runoff and evaporation. In addition, they might be more susceptible to water erosion. Thus, the yield results in the greenhouse must be considered along with physical and chemical characteristics to avoid some misinterpretations.

In this study, multiple regression analyses were run in an attempt to correlate yield with chemical and physical characteristics. For samples from one site, significant correlations were found, but no significant correlations were found when all sites were included. It appears that significant correlations can be found among sites if these are all tested in the greenhouse at the same time. However, different yield levels were obtained for experiments conducted at different times of the year, thus comparisons among sites cannot be easily made. Differences in yield response are believed to be partially due to variations in light response in different seasons.

Inability to correlate results among sites was a major limitation for using our greenhouse data as a calibration tool.

Integrating Greenhouse Yield and Laboratory Data

Data obtained for the Prairie Dog Creek, Montana (Heil and Deutsch 1980a) site are typical of the relationship found between greenhouse yield and laboratory results (Table 1). Criteria developed by our laboratory and based on available interpretive guidelines from several states were used for rating the materials (Heil and Deutsch 1980a). Since N, P, and K were added, these nutrients were considered as nonlimiting. As can be noted from the data, the materials are highly variable in chemical and physical properties.

The trend appears to be that lower yields are associated with higher salinity, although this response is not consistent. In general, lower yields tend to be associated with materials having either one serious limitation or where a number of possible limitations occur. It appears that higher yields tend to be associated with surface materials. The latter and salinity appear to be the factors with which yield is best associated. However, there are inconsistencies relative to all these relationships.

From an interpretive point of view, there are some obvious limitations associated with these data. First, these are some potential interaction effects which could not be isolated or verified. Lack of sufficient materials prevented establishing an experimental design to isolate the effects. Second, factors other than those tested for could have been affecting yield. Third, this data set is too small to treat statistically, and it could not be compared with data from other sites because of reasons described earlier.

However, these data, plus data obtained from other sites, provide a data base from which some definite trends emerge. An example of one of these trends and how it was verified follows.

Testing for Nutrient Deficiencies

Low DTPA-extractable Zn was associated with a majority of both soil and geologic materials with which we worked. A majority of samples tested below 0.5 ppm Zn, which is considered below the critical level for Zn-sensitive agronomic crops. When we began performing plant tissue analyses on plants grown on selected materials, we observed that Zn levels were below those noted for many plants. These trends seemed to emerge from our combined laboratory and greenhouse studies. Finally, we observed what appeared to be evidence of Zn deficiency in plants grown on some materials from the McCallum, Colorado, site, some of which had very low DTPA-extractable Zn levels (Heil and Deutsch 1980e). A small experiment with zinc vs. no-zinc was designed to verify the observation. We obtained a good response to applied Zn on three of the four materials tested (Table 2). The apparent yield decrease in Sample No. 1 material with applied Zn is thought to be an interaction effect with another nutrient but cannot be verified from our data.

The results are insufficient for recommending a critical DTPA-extractable level for western wheatgrass. Significantly, however, the greenhouse studies allowed us to observe soil and plant Zn levels across a wide array of soil and geologic materials, revealing a trend that could be tested. The next step, based on the results obtained in this study, should involve a combined laboratory, greenhouse, and field study to document the need for Zn. It appears doubtful that Zn will be a major limiting factor to successful reclamation in the West. On the other hand, it should not be totally overlooked.

Table 1. Yield and selected chemical and physical data for soil materials from Prairie Dog Creek, Montana.[1/]

				ppm[2/]					ppm[3/]	ppm	ECe[4/]		meq/1		Particle Size		
Sample No.	Depth (in.)	Yield	pH	Fe	Zn	Cu	Mn	% O.M.	P	K	@25°C	ESP	CEC	Texture	%[5/] S	%[6/] Si	%[7/] C
T278	0-12	3.96	7.5	5.2	.58	1.56	11.20	2.60	.75	183	0.69	0.3	16.1	CL	37.7	33.9	28.4
T273	0-18	2.85	7.5	5.1	.54	1.30	11.60	2.30	.75	138	0.52	0.6	15.4	SiCL	10.1	59.3	30.6
T285	0-12	2.77	7.4	9.8	.96	1.62	19.80	2.55	1.63	114	0.72	0.3	15.7	SiCL	17.3	45.4	37.3
T279	12-30	2.60	7.8	6.1	.30	2.32	6.40	1.75	.13	120	0.65	0.6	15.4	CL	35.8	30.0	34.2
T267	0-18	2.04	8.1	5.2	.86	.88	6.30	2.70	3.25	123	0.66	0.7	10.5	VFSL	52.2	32.5	15.3
T289 Control	0-18	1.98	7.9	5.4	.36	1.22	8.60	2.10	.25	72	0.67	0.3	15.4	CL	24.5	44.2	31.3
T289	0-18	1.28	8.0	4.8	.28	1.08	7.10	2.60	.38	48	0.67	0.3	15.4	CL	24.5	44.4	31.3
T284	102-120	1.20	7.7	52.0	.20	1.00	.50	.40	10.40	54	6.79	0.8	15.1	C	7.4	39.4	53.2
T276	48-66	1.05	8.4	4.8	.28	.86	3.00	1.50	3.25	126	10.67	3.1	12.4	SiCL	10.0	57.8	32.2
T268	18-36	.94	8.1	4.0	.40	.70	5.90	1.40	2.25	69	2.30	1.0	8.3	FSL	60.6	24.8	14.6
T280	30-42	.83	8.3	5.0	.24	1.78	2.70	.95	.75	90	1.84	3.2	12.0	CL	37.6	29.9	32.5
T277	0-18	.74	7.5	1.8	.72	.42	3.80	.60	.38	30	7.16	2.7	6.3	SiCL	5.2	62.8	32.0
T260	0-12	.73	7.2	4.1	.30	.28	6.10	1.40	.25	72	1.52	3.5	6.3	FSL	65.3	22.0	12.7
T283	84-102	.71	7.9	66.0	.20	1.56	.60	.40	.99	48	8.98	0.2	12.7	C	11.0	37.6	51.4
T253	0-18	.68	7.8	4.4	.64	1.34	4.80	1.80	1.13	78	1.77	3.4	10.7	L	35.8	37.3	26.9
T270	54-72	.61	8.4	5.2	.96	.90	5.10	1.40	.63	390	9.41	5.2	19.1	FSL	56.3	27.5	16.2
T290	18-30	.58	8.6	3.4	.18	1.02	2.00	1.10	.75	54	1.00	2.0	9.5	L	27.6	46.9	25.5
T286	12-30	.57	8.4	4.7	.20	1.22	3.40	1.70	1.13	63	1.21	3.3	11.1	SiCL	17.6	44.7	37.7
T287	30-54	.57	8.6	6.2	.42	1.36	2.80	3.10	3.88	63	5.14	7.9	15.0	SiCL	6.1	55.1	38.8
T269	36-54	.46	7.8	4.6	.40	.76	4.80	1.10	2.88	153	5.70	4.0	7.4	FSL	68.3	16.3	15.4
T271	72-90	.45	7.7	7.0	1.76	1.10	5.30	1.40	1.38	425	10.68	2.6	8.9	L	48.8	33.4	17.8

[1/] Underlined data are thought to be potentially limiting to plant growth (in the material tested).
[2/] DTPA extractable.
[3/] Sodium bicarbonate extractable.
[4/] Electrical conductivity.
[5/] Percent sand.
[6/] Percent silt.
[7/] Percent clay.

Table 2. Zn response data on selected soil and plant samples--McCallum Site, Colorado

Sample Number	1 Pre-plant first crop available Zn	2 No Zn Post plant available Zn	3 Zn added Post plant available Zn	4 No Zn Plant Zn First Crop	5 No Zn Plant Zn Second Crop	6 Zn added Plant Zn	7 No Zn Yield first crop	8 No Zn Yield second crop	9 Zn added Yield second crop
			ppm				gm		
1	.16	.48	5.8	6	14.5	49.1	.5	1.2	.6
2	.20	.20	5.0	6	5.9	21.6	1.1	1.1	1.9
3	.24	.36	2.8	10	20.6	47.4	.9	.7	1.6
4	.18	.28	6.3	6	11.9	25.6	.8	1.3	2.3

Column 1 = DTPA-extractable Zn level of soil prior to experiment.

Column 2 = DTPA-extractable Zn level of soil which was analyzed after growth of first crop.

Column 3 = DTPA-extractable Zn level of soils which were analyzed after Zn had been applied after growth of second crop. Zn was applied at a rate of 10 lbs. per acre as $ZnSO_3$.

Column 4 = Zn concentration in plants of first harvest.

Column 5 = Zn concentration in plants of second harvest--no Zn added.

Column 6 = Zn concentration in plants of second harvest--Zn added.

Table 3. Mn relationships associated with selected acid soil materials: Arkoma, Oklahoma EMRIA site.

Sample No.	Pre[1/]	Post[2/]	DTPA Ext. Pre	Mn.-ppm Post	Total Plant Mn-ppm	Yield[3/] gm/pot
1	5.2	6.8	0.6	44	259	0.74
2	4.5	4.7	0.9	11	122	0.97
3	4.9	4.3	0.2	59	716	0.66
4	5.1	4.6	1.4	28	81	0.79
5	5.2	5.2	4.0	44	35	0.96

[1/] Pre = Analyses performed before greenhouse test.

[2/] Post = Analyses performed on soils sampled from greenhouse pots after completion of greenhouse study.

[3/] Highest yield obtained from any material during this particular experiment was 1.57 gm/pot.

Table 4. Increases of sodium bicarbonate extractable P and plant response to soils treated with 80 ppm P -- Beulah Trench Site, North Dakota, and Fish Creek, Colorado, Site.

Sample No.		Sodium Bicarbonate Ext. P-ppm Pre-plant[1]	Post Harvest[2]	Total Plant P %
Beulah Trench Site				
Soil Materials	1	3	27	.45
	2	3	35	.39
	3	1	26	.55
	4	1	32	.55
	5	2	33	.38
Geologic Materials				
	1	2	43	.32
	2	1	32	.42
	3	3	33	.76
Fish Creek, Colo., Site				
Geologic Materials				
	1	2	52	.25
	2	1	53	.26
	3	2	41	.10
	4	0	49	.07
	5	2	50	.15
	6	0	53	.07

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[1] Materials analyzed prior to any treatment.

[2] Materials sampled and analyzed following greenhouse study and to which 80 ppm P had been added prior to greenhouse study.

Fate and Mobility of Heavy Metals

A major concern associated with acid materials and/or materials containing sulfides is the fate and mobility of chemical constituents found in these materials--particularly heavy metals. The data presented in Table 3 illustrate some relationships observed with Mn for some acid soil materials from Arkoma, Oklahoma (Heil and Deutsch 1980d). These data demonstrate a dramatic increase in post- vs. preDTPA-extractable Mn and suggest the Mn was approaching a toxic level in plants grown on materials represented by Sample No. 3. These relationships were not revealed by the initial laboratory results. This example supports a trend we observed--that is, often there appeared to be better correlation between plant response and postharvest soil analyses than with preharvest or initial analyses. This suggests potential changes in the chemical nature of materials when subjected to an active biogeochemical weathering environment.

However, some serious limitations associated with our observations existed. Contamination of materials by fertilizer, laboratory error, lack of replication of treatments, as well as other factors may have been responsible for some differences. Lack of sufficient materials and other resources prevented us from further documenting our observations. Our effort proved to be an initial screening of some potential problems which might occur pertaining to the mobility and uptake of heavy metals as influenced by chemical properties of the materials.

Fate of Applied Phosphorus

Available P generally was very low in most materials we tested (Heil 1978). Of interest is the efficiency of applied P to materials which often are characterized by high pH, have free $CaCO_3$ present, and are very finetextured. As shown in Table 4, soil P levels following harvest were very high in all materials, well above the level of 15 ppm considered very high for most agronomic crops. Plant P levels also were very high, indicating a positive correlation between high soil P level and plant uptake (except examples 3, 4, 5, and 6 from the Fish Creek site). The P levels of plants grown on these materials were marginal to deficient. Growth was severely restricted on these materials due to extremely high Na levels--SAR's >50. Thus, a factor other than available P limited plant P level. The results shown in Table 4 are representative of observations obtained from other sites. The greenhouse and associated soil and plant characterization studies allowed us to observe the effectiveness of applied P in soils and geologic materials having widely different chemical characteristics.

Plant Response as an Integrator

Greenhouse yields appeared to be an integrator of many factors. For example, a large number of materials evaluated from the Emery, Utah, site were characterized by being coarse-textured, having a low cation exchange capacity, and a generally low fertility status (Heil and Deutsch 1979). Although these materials were fertilized with N, P, and K and watered daily, yields of western wheatgrass ranged from 0 to 0.26 gm/pot. The highest yield obtained from other materials was 1.72 gm/pot. Analysis of the plant material from those pots indicated levels of most elements were borderline for being adequate. Greenhouse performance on these materials suggested what might be called "subclinical" effects on growth. This same relationship was experienced with regard to a number of materials from a number of sites. That is, often there was no clear evidence of one or several factors which might limit growth. Relative greenhouse performance often was the only indicator that a problem might exist. Again, lack of sufficient materials and other resources prevented further documentation of our observations.

SUMMARY

It is important to point out that greenhouse studies have inherent limitations for evaluating soil-plant-water relationships. However, if developed and planned as part of an overall diagnostic program, these studies can serve as a useful tool for assessing the suitability of soils and geologic materials for reclamation.

The role of greenhouse studies will depend on the situation; that is, they will not always be needed. Specifically, greenhouse studies and associated laboratory analyses can support an overall diagnostic program in the following ways:

1. To isolate and study specific kinds of soil-plant interactions that cannot be easily studied in the field.
2. To serve as an efficient and economical screening mechanism for identifying the kinds of problems which might exist with certain materials.
3. To serve as a basis for designing more effective field studies through problem identification.

The greenhouse method has some basic requirements which must be met if it is to provide meaningful results. To design appropriate experiments, laboratory support data (both plant and soil data), time, facilities, operating support, and an adequate supply of soil or geologic materials are required.

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WILDLIFE AND SURFACE MINING RECLAMATION

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WILDLIFE AND SURFACE MINING RECLAMATION

Introduction

Today's resource managers are faced with the seemingly contradictory demands of developing western coal resources while still maintaining the ecological integrity of the land. This chapter will deal with just a portion of this dilemma: Coal development and wildlife resources. It will present the major wildlife concerns and the procedures currently available to mitigate impacts on wildlife from coal surface mining in the Northern Rocky Mountain and Great Plains Region (NRMGPR).

Like most resource management disciplines, wildlife management is not an exact science. It does not have specific procedures which, if precisely implemented, will always be successful everywhere. New techniques are constantly being developed and each geographic area has its own unique circumstances. Consequently, this chapter will not attempt to provide the definitive solutions to all of the wildlife/mining conflicts. It will however, attempt to present the most current mitigating procedures known. Once these are understood, they may have to be modified on an area to area basis before implementation. Emphasis will be placed on the importance of understanding the entire ecosystem of each location. This holistic approach, viewing the system in its entirety, should give the manager a better opportunity of achieving the ultimate goal: Recreating a complete and appropriate self-sustaining ecological system.

The holistic approach is of paramount importance; putting all the pieces back together again during the reclamation phase will require familiarity with all the parts, biotic and abiotic alike. Recognizing and understanding the interrelationships of all the parts is the integrated approach to resource management. This chapter will cover only the biotic parts, and, more specifically, the "animal" parts. Other chapters will deal with the other parts of the system.

Of all the interrelationships involved in a functioning ecosystem, perhaps the most important is that of the resource manager to the resource. Ultimately, it depends on the individual manager to see to it that all the appropriate procedures are implemented and that all goals are achieved. As wildlife managers, our first concern is to all species of wildlife and whatever our efforts might be, they will be all that wildlife has. If we do less than what is possible, we will have compromised the well-being of the wildlife resources and ultimately, the well-being of the entire ecosystem. The survival of wildlife is now our responsibility; if we fail in our task we may forever hear the silence.

This chapter will attempt to provide the manager with the direction and the means to integrate all of the wildlife concerns with the appropriate mitigating procedures. But, until the resource manager dedicates himself completely to the goal of providing a complete and appropriate self-perpetuating ecological system, there will remain understandable conflicts between the many groups interested in the various western resources and there will be a less than reasonable chance of success for the overall land management program.

A Resource Perspective

Early Views

Historically, wildlife was viewed as a by-product and secondary use of the land; not surprisingly, it received minimal attention during early land management programs. Along with its secondary status, wildlife was arbitrarily, and perhaps unintentionally, divided into groups of beneficial, detrimental, and neutral species. Game species were encouraged, predators were eliminated, and the remaining species were left to survive wherever the circumstances permitted.

In North America, these attitudes first appeared in the eastern United States, where virtually all new lands fell into private ownership and land use patterns were based upon agricultural, mineral, or forest potentials. The beneficial and neutral species survived on lands too marginal for agriculture and on the few areas set aside specifically as wildlife refuges. In many ways, these attitudes have survived to the present and have brought with them a unique and deeply ingrained set of problems.

The first of these problems deals with the practical aspects of management. The secondary status of wildlife species resulted in low management priorities, low budget allocations, and restricted research efforts. Appropriations were used for programs with the greatest pay-back potential; funds were allocated for the popular game species and for the elimination of the detrimental species. The remaining species received little or no management or budgetary attention.

Decades of wildlife management based solely on economic values have taken their toll. Undesirable species, primarily the predators, have been eliminated from most of their former range, while a few of the prime game species, such as deer, upland game birds, and waterfowl have thrived. In fact, many biologists estimate that there are more white-tailed deer in the United States today than there were when the pilgrims arrived. These management programs have resulted in extremely artificial environments, many of which now perpetuate themselves only with intensive human manipulation. Consequently, many areas set aside for wildlife no longer resemble the native potential of the lands. As a result, a large segment of the public has developed a mistrust of the basic desire of today's resource management agencies to manage for the benefit of all wildlife, not only species with economic importance.

New Awareness

Fortunately, these attitudes are beginning to reverse themselves. Wildlife is still viewed as a by-product of the land, but increasingly it is being looked upon as an integral and necessary part of all of the ecological cycles. Resource administrators and the public alike are becoming more aware of the ecological value of wild species and the economic and intrinsic value of intact ecosystems. This new awareness can be seen in the increased (albeit often still inadequate) budgets for wildlife management programs, and in the increased concern for non-game species management, threatened and endangered species management, and the systems approach to resource management.

Unfortunately, management's awareness of ecological systems has brought about another set of problems. On one hand, it is well known that more energy can be made available to the top consumer in the food chain (in this case, man) if the intermediate trophic levels are eliminated and the top consumer can subsist directly upon the primary producers. For example, a unit of land can supply man with more energy if he eats the plants and/or the seeds (grain crops) grown on the land than if he eats the grouse that eat the insects that in turn eat the plants. Proponents of this philosophy see wildlife as an intermediate and wasteful step in the cycle and an obstacle in achieving the ultimate goal of supplying mankind with as much energy as possible, be it food, fiber, or fuel.

On the other hand, as appealing as it may appear, eliminating intermediate trophic levels (animals) is not without its hazards. It reduces species diversity and system complexity. Current ecological thinking equates this with reduced system stability (Odum 1971; p. 150, 256). Once components are removed, the system becomes more vulnerable to outside perturbations (Meyers 1980). This problem can be partially rectified by increasing artificial management. For example, chemicals can be administered to the system to, 1) control competitors (weeds and insects), 2) stimulate production, and 3) replace lost chemical elements and generally replace the effects of the lost components. But few ecological systems are so well understood that major natural elements can be successfully replaced with sophisticated management techniques. For example, some of this nation's most productive and highly managed lands, those found in Iowa and Illinois, once contained hundreds of species of prairie plants and animals per hectare. This tall grass prairie, without sophisticated human input, perpetuated itself and produced some of the richest topsoil on this continent. But now that over 99 percent of that land has been altered and the majority put into agriculture, half of the farms are losing topsoil at a rate of 10 to 20 tons per acre per year (USDS 1981). This is occurring in spite of the application of state-of-the-art agricultural practices, including infusions of energy and agricultural chemicals. Admittedly, these intense land use practices are now supplying the world with a large amount of food and fiber, but the system itself is unstable, inefficient, and running downhill. If the current trends continue, the topsoil and productivity will disappear and mankind will have created yet another temperate desert.

Thus we have two choices: Simplify the system, increase short-term productivity, and run the risk of having the system deteriorate and eventually become unproductive; or, retain as many elements of the natural system as possible, maintain or perhaps improve current productivity, and sustain the systems for the future. As land managers responsible for the immediate and long-term well-being of the public resources, the choice should be obvious: We must work within the natural systems.

Reality Of Current Conditions

A point often overlooked when management plans are being considered is that most of our western lands have already been severely altered. Gone from the plains are the bison, wolf, grizzly bear, and elk. Reduced by 95 percent are the prairie dogs and pronghorn antelope. The black-footed ferret is almost extinct. Greatly reduced are the burrowing owls, prairie chickens, and sharp-tailed grouse, and gone forever is the Audubon's bighorn sheep. We can only guess how many other species have already been lost, before we had an opportunity to know them. As a result, current conditions should not be used as the only yardstick by which to determine reclamation efforts. If we continue to ignore what has already been lost and assume that what exists now represents the greatest potential of the land, we will be perpetuating past mistakes.

Whenever reclamation plans are being drawn up, the historic as well as the contemporary components should be considered. Efforts must be made to restore even those elements which were lost before the current mining operations began. Obviously, not all the biotic features can be replaced, but those that can, should. The final decision will have to be made cooperatively by all the management agencies, but it must be understood that nothing short of a complete species review is acceptable.

Today's Public Opinion

Today's public has a clearer understanding of the interrelationships of living organisms: no longer is the worth of a species determined by artificial human values. A significant segment of the population understands the importance of intact ecosystems and their role in sustaining all life. The public now expects resource management programs, particularly those on public lands, to reflect this understanding.

The task of managing wildlife resources in the West is made easier because, unlike the eastern United States, so much of the land is publicly owned, wildlife management can begin from the ground up with sound land and habitat management programs. A large segment of the public now realizes that an integrated resource management program with a holistic approach is not only possible but necessary.

The Future--Which Way Now

Once all of the above concerns have been addressed and the reclamation and management programs are established, managers must address yet another question which may not appear pertinent at this time: Shall the land be allowed to evolve through its inherent transitional stages or shall it be artificially held at a pre-determined seral stage, beneficial to a particular plant/wildlife species composition?

This question demands a very long-term vision of the management process. On newly reclaimed lands it may not be relevant for ten or twenty years but on land already containing a compliment of established biotic components, the question has importance today. Are we to burn ponderosa pine encroachments into the grasslands in order to provide grazing habitat for ungulates and cover for upland game birds? Shall lodgepole pine advancements into sagebrush be stopped? Shall pinion-juniper stands and sagebrush be chained to provide more forbs and grasses? All of these alternatives and many more represent an attempt to control or not to control natural succession. Obviously the various choices can yield quite different results.

Because of the public's awareness of the ecosystem approach to management, the practice of controlling habitat succession is coming under close public scrutiny. For example, in the eastern United States, large tracts of habitat are being artificially held at early successional stages in order to support large populations of white-tailed deer. Many citizens groups have taken this type of management to task because they argue that other species, also native but of less economic importance, can not survive in these controlled situations. The old value systems are being challenged, management programs based on economics and single species concerns are giving way to the desire to manage the entire ecosystems. Unfortunately, the issues have often been clouded by emotionalism, hunting groups support the management programs that enhance white-tailed deer populations are being opposed by anti-hunting elements who want the habitat to be free to evolve and to create the mosaic of different habitat types which will in turn support a wide variety of wildlife species.

In the West, the issues and groups are not yet as clearly defined, but the attitudes are beginning to emerge. To head off the type of conflict which has unnecessarily polarized groups in the East, today's western land managers will have to be responsive to a broader set of interests and have to adopt contemporary systems management philosophies and incorporate state-of-the-art techniques into their management programs.

Resource Inventory - The First Step

According to the National Academy of Sciences report entitled "Rehabilitation Potential of Western Coal Lands,"

> "Rehabilitating disturbed areas for animal habitat is of great importance and should be a primary consideration in designing and reshaping the spoil material and in selecting plant species to meet habitat requirements. In general, the best habitat for native animals is one similar to the habitat in which the species evolved.

> Therefore, the more closely that conditions prior to mining are approximated, the more suitable will be the results for native animals that were on the site previously. However, if new species or a greater variety of animals are desired, a still greater diversity in plant cover also is desired."

Though the scientific method is most often applied to research, its application to wildlife management should be obvious; it establishes procedures which will help resource managers meet their obligations to the law and the resource. For this purpose, the six steps of the scientific method can be modified to fit the coal surface mining reclamation process:

1. Observations--To reclaim the site to a condition as good or better than that which existed before mining, a pre-mining inventory must be performed. This will document and evaluate the biotic resources and will provide the information on which the mitigation procedures can be based.

2. Hypothesis--Understanding that the overall objective of the reclamation program is"...to maintain and re-establish on and near the disturbed site a viable, self-sustaining community of wildlife populations representing as nearly as possible the former and potential species diversity and densities." Then the best and most current mitigating and enhancement techniques will have to be sought out and incorporated into a reclamation plan acceptable to all parties.

3. Test Hypothesis--Testing the hypothesis simply means initiating the mitigating and enhancement procedures agreed upon in the reclamation plan.

4. Interpret Results--Interpreting the results will be accomplished through a long-term monitoring program agreed upon in the reclamation plan.

5. Conclusions--As a result of the monitoring program, it will be determined if the objectives of the reclamation plan have been realized. If not, the legal conditions of the agreement will force the resource manager to develop and initiate new techniques.

6. Report Conclusions--When the conclusions have been reported and it is agreed that all the objectives have been achieved, the final report will be accepted and the performance bond can be released.

Based upon the mining sequence, the complete reclamation program can be viewed in three parts: the pre-mining inventory, mine operating procedures, and the post-mining or reclamation/enhancement period. Table 1 provides a matrix of how and when the different phases of the management plan should be carried out.

Inventory: Objectives and Procedures

The responsibility of the wildlife manager begins with the pre-mining activity, which includes the initial site exploration and mapping activities. The thoroughness with which the resource manager conducts the pre-mining activity will directly influence the outcome of the overall management plan.

TABLE 1. IMPLEMENTATION SEQUENCE FOR THE DIFFERENT PHASES OF THE RECLAMATION PLAN AT A COAL SURFACE MINE SITE.

	PRE-MINING	MINING	POST-MINING RECLAMATION/ENHANCEMENT
OBSERVATIONS	Biotic Resource Inventory: -Map habitat types. -Evaluate conditions of habitat. -Inventory wildlife: Distribution, density and habitat affinities.	Biotic Resource Inventory continues on the as yet undisturbed mine-site land.	
PREPARE RECLAMATION/ MANAGEMENT PLAN	The reclamation/management plan must contain an estimate of the kind and degree of impact on the biotic resources and determine which of the best available techniques are to be used to minimize and mitigate the impact and which to use to reclaim and enhance the area after mining. The post-mining land use plan must be clearly defined.		
BEGIN RECLAMATION/ MITIGATION/PROGRAM	Begin the pre-mining mitigation procedures which can prevent adverse impact to biotic resources. (Transplant, alternate rapter nest site construction etc.). Enhance adjacent habitat.	Initiate mitigation procedures which are to be operative during mining operation.	Continue reclamation/ enhancement procedures.
MONITOR PROGRAM		Initiate monitoring programs to evaluate success of mitigation programs.	Initiate and continue monitoring programs to evaluate success of mitigation, reclamation and enhancement programs.
FINAL REPORT-RELEASE OF PERFORMANCE BOND			Final report preperation and site inspection in accordance with management plan objectives subsequent to performance bond release.

The regulatory authorities and management agencies within the State where the mining activities are to be conducted should be contacted immediately. In some States, the local wildlife management agencies will have complete authority over the biotic resources, while in others the Federal Office of Surface Mining will have primacy. In either case, all regulations pertaining to the protection and enhancement of the biotic resources should be followed.

If the proposed mine site is being leased from private landowners, then a meeting of the operators, landowners, and regulatory agencies should be held. At this time the post-mining land use goals should be agreed upon and coordinated with the requirements of the State and Federal regulatory agencies.

Most States have laws comparable to the Surface Mining Control and Reclamation Act of 1977, which allows for the denial of a mining permit on the basis of irrevocable loss of critical wildlife species and wildlife habitat. (For the remainder of this chapter, the word critical is used collectively to mean those species variously listed as being important, sensitive, rare, threatened, or endangered by Federal and/or State agencies.) The Federal Coal Management Report (1980 p-B-1, B-2) describes seven specific examples of "...assessing lands unsuitable for all or certain stipulated methods of coal mining." These include critical habitat for Federal and State listed threatened and endangered species, bald and golden eagle nesting and roosting sites, falcon cliff nest sites and support habitat, important migratory areas for both birds and game mammals, and critical areas such as grouse strutting grounds. Only after these concepts, goals, and regulations are understood can the biotic resource planning process begin.

The major objectives of the pre-mining inventory are listed below:

1. Develop a list of the species historically occurring in the area of concern.

2. Develop a list of wildlife species actually occurring on the area.

3. Develop a list of the major historic habitat types in the area.

4. Map and evaluate the condition of current major habitat types.

5. Obtain relative population densities for major and critical wildlife species.

6. Determine habitat affinities for major and critical wildlife species.

7. Determine seasonal habitat use patterns and migratory routes for major and critical wildlife species.

An important element of the inventory process and one which is often neglected is the search of the historic literature. This must be done to identify the biotic elements that were native to the area. This information will provide an indication of the site potential and provide baseline information from which to evaluate historic changes.

Literature describing the ecological conditions at the proposed mine site will probably be lacking. Consequently, this information will have to be extrapolated from publications describing similar areas. Some of the earliest accounts come from the journals of the first explorers to enter the NRMGPR. Several of these accounts as well as some contemporary reviews of wildlife populations are listed below:

Audubon, J. J. and J. Bachman. 1849-1954. The Viviparous Quadrupeds of North America. 3. vols.

Bailey, B. 1926. A Biological Survey of North Dakota. North America Fauna Series. No. 49. Wash. D.C.

Cary, M. 1911. A Biological Survey of Colorado. North America Fauna Series. No. 33. Wash. D.C. North America Fauna Series. No. 42.

Thwaites, R. ed. 1969. Original Journals of the Lewis and Clark Expedition, 1804-1806. 8 vols.

Matthiessen, P. 1959. Wildlife in America. Viking Press. New York. Penguin Books. 304 p.

Allen, D. 1954. Our Wildlife Legacy. New York. Funk and Wagnalls. 422 p.

Next, the recent scientific literature must be searched to provide a list of the species currently inhabiting or potentially inhabiting the area. The accuracy of this list will depend on the diligence of the investigator and his ability to discern one habitat type from another. Additional information can be obtained from the records and from individuals of the various State and Federal agencies dealing with the wildlife resources in the area. The value of communicating with the individuals already working in the area cannot be overemphasized. Information can also be obtained from university personnel familiar with the area and from university museum collections. Conversations with long-time residents of the area can often result in valuable information and can generally provide a unique perspective for the resource manager.

It will become apparent that the bulk of the available information will deal with game species, detrimental species, and highly visible species. Little published information will be available for groups such as the amphibians and reptiles.

Comparisons of the historic and current species lists will document the changes which have already occurred. It is not the responsibility of the mine operator or the resource manager to reestablish the environmental components lost prior to the onset of the mining operations. However, the historic species list will provide an indication of which elements might be brought back during the reclamation process. This becomes significant if the condition of the site prior to mining was so altered from the historic environment that restoring the site to pre-mining conditions would not be beneficial to wildlife.

Several publications will help the resource manager determine the amount of habitat change that has already occurred:

Bailey, R. 1978. Descriptions of the Ecoregions of the United States. USDA Forest Service. Inter. Mtn. Reg., Ogden, Utah. 77 p.

Kuchler, A. 1964. Potential Natural Vegetation of the Conterminous United States (map and manual). Am. Geog. Soc. Spec. Pub.

Shelford, V. 1913. Animal Communities in Temperate America. Chicago. Univ. Chicago Press. 368 p.

---1963. The Ecology of North America. Chicago. Univ. Ill. Press. 610 p.

Next, a list should be compiled of all of the critical species known or thought to occur in the area. Most State and Federal resource agencies have lists of these species with their known or expected distributions and habitat affinities. Critical species here will include those listed as threatened or endangered by the Secretary of the Interior and those warranting special management attention by local wildlife management agencies. They may include the indicator species, species considered to be locally rare, threatened, or endangered.

By knowing which critical species to expect, specific inventory procedures can be included in the mine plan. This will increase the efficiency of the inventory method and reduce the time and resources spent on unnecessary search efforts.

The concept of a critical resource also applies to habitat. Habitat is made up of the physical, or abiotic features (soils, topography, altitude, latitude and climate), and the biotic (plant and other animals) features of the immediate surroundings. A species instinctively selects the habitat to which it is best adapted; this is referred to as its preferred habitat. Some species can exist within a broad spectrum of habitat types, while others are quite restricted. Species with restricted habitat requirements are most severely threatened by habitat alterations because they have few other situations in which they can exist. Species with broad habitat tolerances are usually the least threatened by moderate habitat alterations.

Some species with broad habitat tolerances often exist in less than optimum conditions. This is referred to as suitable habitat, and under these conditions, the species is usually less abundant and exists in lower densities than when found in its preferred habitat. When occurring in marginal habitat, a species may be uncommon or even rare. The differences between preferred, suitable and marginal habitat is often subtle, apparent only with careful analysis. It may be determined by slope, aspect, soil texture or moisture, plant cover, latitude, or altitude. Before the arrival of modern man, these features were determined naturally; now, however, the distribution and the very existence of many species is determined by the changes we have brought to the land.

Habitats are generally named after the dominant or most conspicuous plant species. However, most large wildlife species are not confined to one habitat throughout their lives. Often the various food, cover, and reproductive areas required by a species are significantly different and widely separated. Moreover, the requirements of a particular species may vary from different age and sex classes as well as throughout the year. Therefore, it is often difficult or misleading to link a species with a particular habitat type identified by a single plant species.

Habitat can become critical for a species if it contains specialized environmental components required for the completion of a species' life cycle and if these components are in short supply for whatever reason. Then the wildlife species dependent upon that habitat component will suffer a decrease in vitality and/or numbers. For example, although the NRMGPR contains an abundance of mule deer summer range, much of this range is unavailable to the deer during the winter because of deep snows. Consequently, the deer migrate to preferred winter range, usually on south-facing slopes and ridgetops where snow melts and/or blows off and native forage remains available. If these ridges are suddenly unavailable, for whatever reason, the deer will be without forage and will either die or suffer reduced reproduction and herd vitality. They can seldom, as is often believed by the lay community, simply go to another area, because these other areas either already support a deer population or they provide far poorer range. The winter range is the "bottleneck" or weak link in the deer's life cycle and consequently it takes on a critical aspect for the deer. If a proposed mine encompasses a deer winter range or blocks access to that range, the effect on the deer and what can be done to mitigate this effect must be addressed.

Any management effort which neglects to identify the bottleneck period in a species' life cycle or ignores the concept of critical habitat will likely fail, even though all other components of the life cycle are accommodated.

It is in regard to critical habitat that the dependent relationship of wildlife to habitat is most conspicuous. Throughout this report, information will be presented intended to aid in the protection and enhancement of the wildlife resource. The majority of this material will deal with the manipulation of the habitat--in some cases, the abiotic features but in most cases the biotic components. These include plant species composition, density, and structure, as well as their distribution and availability. These and all the other parameters of habitat must be collectively used to determine the habitat quality for each wildlife species under consideration.

The idea of critical habitat is not confined to plant species occurrence, density or composition. In many situations the very structure or form of the plants is of more importance to wildlife than the species composition. For example, most large raptors require elevated sites for nesting. These can be provided by large aspens, cottonwoods or even coniferous trees. In fact, trees can often be replaced for nesting purposes with man-made structures or cliff faces. To call golden eagle habitat open sage and grasslands would be incomplete if the critical requirement of an elevated nest site was ignored. The latter can become the critical element if in short supply.

For some species, the physical characteristics of the substrate may dictate whether or not an area provides suitable habitat. For example, prairie dogs may find adequate vegetation available at a particular site but if the substrate consists of shallow, impervious soils or is underlain with rock, they may not be able to dig deep enough to provide themselves with year-round (particularly winter) shelter.

Resource Survey Techniques

Numerous techniques are available for inventorying the major wildlife groups. It is not the purpose of this report to review all of these procedures. The major publications describing inventory techniques are listed below:

Call, M. W. 1981. Terrestrial Wildlife Inventory - Some Methods and Concepts. USDI/BLM - Tech. Note 349.

Giles, R. H., (ed.). 1969. Wildlife Management Techniques. Wash. D.C. The Wildlife Society. 623 p.

The first publication is the single most complete reference and guide to inventory techniques applicable to this region, while the second publication provides a broader spectrum of general survey procedures along with management techniques.

In addition, each State wildlife agency has its own field techniques handbooks for use by its own biologists. In many cases, coordinating anticipated inventory techniques with the State agencies will allow the new data to be immediately "plugged" into the existing information network. If few data currently exist, the manager can use his own methodologies, but should still confer with local investigators and use the most appropriate techniques.

Whatever techniques are used, several points should be remembered. First, consistency is of paramount importance. If the same procedure is not followed time after time, the results are apt to reflect the differences in techniques rather than the changes (or constancy) in the biotic resources being surveyed. It is usually more important to have constancy of methods than to have the latest in techniques or equipment.

Constancy can only be achieved if the methods are clearly outlined and followed. This includes accurately pin-pointing on maps the sample areas and the locations of all observations as well as keeping detailed field notes of dates, time, weather conditions, and any other important environmental features. Not only will this help the investigator to duplicate his own efforts but it will also allow a new investigator to continue the work should it become necessary.

Before any field inventory work can begin, the investigator must decide which of three types of data are required. The first, species occurrence, indicates which species occur in the area, usually within each habitat type.

This is the basis for the species lists already mentioned. The disadvantage of collecting only species occurrence data is that it demonstrates only presence or absence--i.e., a species with only one representative appears as boldly on the list as a species with 100 representatives.

Relative abundance is calculated by taking the number of individuals of each species and dividing it by the total number of individuals of all species in the sample. The result allows the species to be ranked from most abundant to least abundant.

Species abundance can also be presented in terms of abundant, common, uncommon, and rare. To make these terms meaningful, they must have standard definitions. The BLM Manual (Section 6602) defines six relative abundance terms for major wildlife species and groups. The biggest disadvantage of using relative abundance is that it is vulnerable to investigator subjectivity and detects only large-scale changes of one population in relation to another. If all populations change proportionately to one another, the shift will not be apparent with relative abundance data.

The most sophisticated and detailed method of inventorying populations consists of determining absolute densities. This method attempts to determine the actual numbers of each species per unit area. This approach is the only one that gives the investigator an actual population estimation and the only method that actually allows all population shifts to be detected.

Obviously, the absolute density method is the most complete of the three approaches and requires the most refined techniques and the greatest expenditure of time and money. Not all situations and species demand this level of investigation. The important point to remember is that before any work begins, the types of data required and the exact techniques to use must be agreed upon by all parties and clearly described in the reclamation plan. Once the procedures are established, they must be maintained throughout the inventory and monitoring process to ensure continuity.

A brief outline of the general level of investigation appropriate and practical for the major wildlife species is provided in Table 1. It must be remembered that with every situation, select species or groups of species may take on differing importance and consequently the level of investigation can change. The general rule is that the more important the species, the more detailed the inventory procedures should be.

Once the inventory procedures are decided upon, it is necessary to locate the sites to be surveyed. These sites should include all of the major habitat types and all of the areas suspected to contain critical species. In most situations, the major habitat types within a 3-km radius of the proposed mine site should also be included in the sample area for the following reasons:

1. Because of the mobility of many wildlife species, individuals and populations not always residing on the site may be affected.

2. Adjacent, undisturbed areas serve as a control with which the effects of the mining, enhancement, and reclamation efforts can be compared.

3. Adjacent areas will provide the reservoir from which individuals may move onto and repopulate the reclaimed site.

All major habitats should be surveyed in proportion to their abundance unless critical habitats or species dictate additional efforts in specific locations.

The undisturbed plots acting as control sites should be as similar as possible in slope, aspect, soil and vegetation type and structure to the disturbed site. All control plots should be permanently marked and identified with steel posts as well as being marked on aerial photographs and geological maps.

Federal and State laws require collecting permits for the capture or disturbance of most species of wildlife. Thus, the U.S. Fish and Wildlife Service Regional Office and the State wildlife agency must be notified before inventory work begins. These agencies will give advice on the types of permits required for the inventory techniques proposed.

Mitigation, Reclamation, and Enhancement Programs

Because of the tremendous diversity of topography, climate, and vegetation found throughout the NRMGPR it is impossible to provide management practices which will always work everywhere. Presented here are practices that work in given conditions and can usually be modified to work in slightly different situations. They are intended to give direction to the program and encourage the implementation of the best possible techniques available. Site-specific plans must be worked out through consultation and coordination with the appropriate State and Federal wildlife management agencies.

Several publications deal specifically with coal surface mining and fish and wildlife needs. These are listed below, followed by brief statements of their content and usefulness.

USDI FWS/OBS. 1977. An Environmental Guide to Western Surface Mining. Part One: Federal Leasable and Locatable Mineral Regulations: An Environmental Guide for Resource Managers. FWS/OBS-77/20. 69 p.

This document provides a thorough review of the specific Federal Surface mining regulations which relate to fish and wildlife concerns.

Munshower, F. and S. Fisher (Co. Chm.). 1982. Proceedings of a Symposium: Mining and Reclamation of Coal Mined Lands in the Northern Great Plains. Montana Agric. Exp. Sta. Research Rept. 194 p.

This publication presents the most up-to-date overview of the major elements involved in the entire surface mining process as it pertains to this region.

Townsend, J. E. and R. J. Smith (eds.). 1977. Improving Fish and Wildlife Benefits in Range Management. USDI FWS/OBS-77/01, 118 p.

This publication provides an insight to the human concerns associated with restoring wildlife habitat in the West.

USDA Forest Service. 1982. Wildlife User Guide for Mining and Reclamation. USDA For. Ser. Gen. Tech. Rept. INT-126. 77 p.

This work summarizes and discusses concerns for the resource manager working in the minerals management area of the western United States. It outlines the considerations which should dominate the thinking of the resource manager. It is not a handbook of methods and procedures, but every resource manager should read pages 38-41 to better understand the major wildlife considerations before attempting to assess the effects of mining on wildlife. It also has an excellent literature cited section containing references to many government publications.

Samuel, D. E., J. R. Stauffer, C. H. Hocutt and W. T. Mason (eds.). 1978. Surface Mining and Fish and Wildlife Needs in the Eastern United States. USDI FWS/OBS-78/81. 386 p.

Leedy. D. L., W. T. Mason Jr. and C. T. Cushwa. (eds.). 1981. Coal Surface Mining Reclamation and Fish and Wildlife Relationships in the Eastern United States. Vol. I, USDI FWS/OBS-80/24 and Vol. II, USDI FWS/OBS-80/25.

The first publication discusses all facets of the mining and wildlife management program, from planning to mitigation, in the eastern United States. The second publication presents the most current sources of information on reclamation and wildlife needs, again for the eastern United States. Although these publications stress the eastern United States, they provide excellent direction for all land managers.

Hinkle, C. R., R. E. Ambrose, and C. R. Wenzel. 1980. A Handbook for Meeting Fish and Wildlife Information Needs to Surface Mine Coal. (Draft). USDI FWS/OBS-79/48.3.4. 388 p.

This publication provides the best information for immediate application by land managers dealing with wildlife and surface mining. It deals with select situations and species and although it emphasizes eastern situations, most procedures can be easily modified for western management purposes.

Moore, R. and T. Mills. 1977. An Environmental Guide to Western Surface Mining. Part Two: Impacts, Mitigation and Monitoring. USDI FWS/OBS-78/04.

Dittberner, P. L. (Proj. Off.). 1978. Rehabilitation of Western Wildlife Habitat: A Review. USDI FWS/OBS-78/86. 239 p.

The first publication describes regional ecology and mining procedures, details the effects on the resources of each step of the mining operation, and recommends ways to reduce these effects and monitor the results. The second publication describes in detail the habitat requirements of major wildlife species and tells how to maintain and achieve these requirements during the mining program.

Habitat Reclamation Considerations

Without going into detail on how to reestablish all the plant components (these are presented in the vegetation section of this handbook), let us review the objectives of the habitat restoration program in terms of meeting wildlife needs.

1. Restore vegetation which most accurately reflects the historic native plant communities and which is compatible with existing undisturbed adjacent vegetation.

2. Where possible, create a mosaic of plant species including patches of the different species but avoid large monocultures (areas containing only one species).

3. Restore habitat diversity, by maintaining topographic diversity through proper site contouring and soil handling and replacement.

4. Increase habitat diversity by including shrubs and trees in the revegetation plan. This vertical dimension to the habitat provides food, cover, nesting areas, and perching sites for many species of birds that might not otherwise use the site.

Referring back to the holistic approach to resource management, it becomes apparent that habitat diversity helps stimulate wildlife diversity. It should also be apparent that habitat diversity is influenced by topographic and soil variability. Minor changes in topography--the degree of slope, slope aspect, and rock outcrops--all provide the physical variability necessary to establish microclimates that in turn result in micro-environments and habitats.

The reason for using native plants in the reclamation program stems from two basic premises. First, native species should be best suited to the area, having evolved with and adapted to the local conditions. Second, the historic native plant communities provided the habitat in which the native wildlife species evolved. Substitutions may be made when native plant seeds and/or root stock are not available or are too costly. Plant species should be selected on the basis of: 1) their ability to survive and perpetuate themselves; 2) their ability to act as nurse crops for other desirable species; 3) their value to wildlife as food and/or cover; 4) their ability to provide a starting point from which the site can evolve to a more desirable seral stage; 5) their ability to protect the site from erosion; and 6) their availability and cost of handling and seeding.

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Bailey, R. 1978. Descriptions of the Ecoregions of the United States. USDA Forest Service. Inter. Mtn. Reg., Ogden, Utah. 77 p.

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USDI FWS/OBS. 1977. An Environmental Guide to Western Surface Mining. Part One: Federal Leasable and Locatable Mineral Regulations: An Environmental Guide for Resource Managers. FWS/OBS-77/20. 69 p.

Munshower, F. and S. Fisher (Co. Chm.). 1982. Proceedings of a Symposium: Mining and Reclamation of Coal Mined Lands in the Northern Great Plains. Montana Agric. Exp. Sta. Research Rept. 194 p.

Townsend, J. E. and R. J. Smith (eds.). 1977. Improving Fish and Wildlife Benefits in Range Management. USDI FWS/OBS-77/01, 118 p.

USDA Forest Service. 1982. Wildlife User Guide for Mining and Reclamation. USDA For. Ser. Gen. Tech. Rept. INT-126. 77 p.

Samuel, D. E., J. R. Stauffer, C. H. Hocutt and W. T. Mason (eds.). 1978. Surface Mining and Fish and Wildlife Needs in the Eastern United States. USDI FWS/OBS-78/81. 386 p.

Leedy. D. L., W. T. Mason Jr. and C. T. Cushwa. (eds.). 1981. Coal Surface Mining Reclamation and Fish and Wildlife Relationships in the Eastern United States. Vol. I, USDI FWS/OBS-80/24 and Vol. II, USDI FWS/OBS-80/25.

Hinkle, C. R., R. E. Ambrose, and C. R. Wenzel. 1980. A Handbook for Meeting Fish and Wildlife Information Needs to Surface Mine Coal. (Draft). USDI FWS/OBS-79/48.3.4. 388 p.

Moore, R. and T. Mills. 1977. An Environmental Guide to Western Surface Mining. Part Two: Impacts, Mitigation and Monitoring. USDI FWS/OBS-78/04.

Dittberner, P. L. (Proj. Off.). 1978. Rehabilitation of Western Wildlife Habitat: A Review. USDI FWS/OBS-78/86. 239 p.

In the revegetation program, species composition should include (whenever environmental conditions permit) a minimum of six species of native grasses, forbs, and shrubs. Instead of planting all species evenly over the site, certain species should be clumped where site conditions indicate their greatest prospects of success. A mixture of several plant species will provide a year-round source of food for wildlife, since the different species will become available at different times of the year. Mixed species will also provide a mixture of cover types and will, as a community, be more adaptable to environmental fluctuations.

Some annuals should always be included in the seed mixture. These species will show the greatest first-year growth, thereby providing immediate protection to the soil and food and cover for some forms of wildlife. The exact seed composition should be determined with the aid of State wildlife management personnel and will have to meet their approval.

Whenever possible, strips or islands of land should be left undistrubed throughout the mining operation. These areas will provide reservoirs (both plant and animal) from which the reclaimed site can be repopulated naturally. Natural repopulation is the least expensive and will help insure the establishment of native species.

The following publications provide basic information about reclaiming disturbed sites for wildlife:

Plummer, A P., D.R. Christensen and S.B. Monsen. 1968. Restoring Big-game Range in Utah. Utah Div. Fish and Game. Pub. No. 68-3. 183 p.

Wyoming Game and Fish. 1976. Considerations for Wildlife in Industrial Development and Reclamation. 65 p.

Agricultural-Wildlife Habitat

Many areas being considered for surface mining will be reclaimed for agricultural uses, either as range land or crop land. Unfortunately, many resource managers believe that once land is considered for agricultural purposes, little can (or should) be done to benefit wildlife. But, from a wildlife standpoint, even apparently insignificant gestures can greatly enhance wildlife populations. For example, fencelines, drainages, swales, and odd corners (fence corners and ridgetops) left in native plant species, even if only 2 m wide, can provide cover for many small mammals and ground-nesting birds. Provisions such as these will also provide year-round soil protection from wind and water erosion.

In planning for wildlife habitat in conjuction with agricultural uses, several points should be remembered. First, no site is ever too small to be of some wildlife value. Second, wildlife habitat which occurs along narrow drainages, fencerows and other long, narrow features can be improved if large islands of habitat (15 to 50 m across), tangential strips of habitat, or even sections of non-habitat are included. The reason for this is that narrow strips of habitat confine wildlife species and, consequently, wide-ranging predators often follow these strips with a devastating impact on the prey species, particularly nesting birds. By creating wide habitat spots, tangents, and breaks, the prey can utilize a two-dimensional distribution within the habitat and increase their chances of remaining undetected.

Because of the limited area involved with many of the agricultural-wildlife habitat units, the value to wildlife, particularly birds, can be increased by including shrubs and trees on the site. This adds a vertical dimension to the habitat and enables individuals to escape ground predators and provides habitat for non-ground-dwelling species.

The species selected for planting in the strips adjacent to crop lands should not grow taller than their distance from the crops. This will insure that the habitat strips will not shade the cropland and thus reduce crop productivity.

Wildlife values can be enhanced if a strip of cropland (2 to 4 m wide) is left unharvested along the wild habitat. This will provide additional wildlife food and cover during the winter months.

Reclamation plans intended to provide grazing lands should avoid seedings of single species (monocultures) such as crested wheatgrass. Monocultures, besides being ecologically unstable, provide very limited wildlife value. Monocultures of crested wheatgrass have been shown to have a negative effect on bird species and population densities (Hickey and Mikol 1979; Reynolds and Trost 1979).

Reclaimed agricultural grazing lands should contain a mixture of as many native plant species as possible, including annuals, perennials, forbs, and shrubs (particularly sagebrush). Such diversity will generally provide more year-round productivity and will also be many times more beneficial to wildlife than monocultures or plantings of domestic species.

Depending on site conditions (soil moisture and fertility) and the species planted, grazing should not occur until the plants have gone through at least two growing seasons (Plummer *et al.* 1968). This interval can change, depending on the type and amount of grazing. Light summer grazing can occur sooner after revegetation than can concentrated, heavy grazing on winter range. Soil fertility, moisture, site slope, and elevation will also affect the amount of grazing a site can withstand.

Fences and Wildlife

The most likely function of fences in a reclamation plan is to keep some or all ungulate species from newly seeded areas or to keep them from areas of special concern (riparian vegetation). Whatever their intended purposes, fences can be designed in many different ways to achieve the desired goal.

The following publications provide information for fences:

Anderson, L.D. 1980. Adjustable Wire Fences for Facilitating Big Game Movement. USDI/BLM Tech. Note 343. 7 p.

Yoakum, J. and W.P. Dasmann. 1969. Habitat manipulation practices, pgs. 173-232. In: R.H. Giles, Jr. (ed.), Wildlife Management Techniques. The Wildl. Soc., Wash. D.C.

Vallentine, J.F. 1971. Range Development and Improvements. Brigham Young Univ. Press. Provo, Ut. 516 p.

The wire mesh fence is the most efficient design for restraining both sheep and cattle. It should be at least 75 cm (30 in) above the ground and have two barbed wire strands 95 and 115 cm (38 and 46 in) above ground. This fence design will also contain antelope, but not other wild ungulates.

A three-strand barbed wire fence 76 to 91 cm (30 to 36 in) high is sufficient to restrain cattle.

To restrain white-tailed deer, a mesh fence should be used. It should be at least 183 to 213 cm (6 to 7 ft) above level ground, and if in an area of deep snow accumulations or if the fence extends perpendicularly to the fall line of a steep hill, the fence should extend an additional 30 to 60 cm (1 to 2 ft). A 213- to 244-cm- (7- to 8-ft-) high fence is required to contain mule deer on level ground and a 300- to 330-cm- (10- to 11-ft-) high fence will be necessary on hilly ground or in areas of heavy snow accumulation. Overhanging or slanted fences do not function properly in high snow accumulation areas and should be avoided.

Antelope-proof fences should be constructed of woven mesh measuring no more than 10 by 15 cm (4 by 6 in) and need not be higher than 81 to 91 cm (32 to 36 in). Most antelope prefer to crawl under fences; care should therefore be taken to keep the fence tight to the ground.

Additional information on fences can be found in individual species accounts.

Forest Habitats and Wildlife

Brief consideration will be given to mining, mitigation, and reclamation efforts in forest habitats. In this discussion, the mere presence of trees will be viewed as forest habitat, i.e., they need not be the dominant plant species

Trees--young, mature, or dead--all provide important habitat for a variety of wildlife species, including nesting sites for birds and squirrels, perching sites for raptors, and feeding habitat for the myriad bird species which consume foliage, seed parts and insects associated with the tree. Trees simply add an entirely new dimension to the site and increase overall diversity within the ecosystem. The following publications discuss the values of forest habitat for wildlife:

USDA Forest Service. 1980. Workshop Proceedings: Management of Western Forests and Grasslands for Nongame Birds. USDA For. Ser. Gen. Tech. Rep. INT-86. 535 p.

USDA Forest Service. 1975. Proceedings of the Symposium on Management of Forest and Range Habitats for Nongame Birds. USDA For. Ser. Gen. Tech. Rep. WO-1. 343 p.

Dittberner, P.L. 1978. Rehabilitation of Western Wildlife Habitat: A Review. USDI FWS/OBS-78/86. 238 p.

Thomas, J.W. (ed.). 1979. Wildlife habitats in Managed Forests: The Blue Mountains of Oregon and Washington. USDA For. Ser. Handbook No. 553. Pacific Northwest Forest and Range Exp. Sta., 512 p.

Forest ecosystems provide a wide variety of wildlife habitat elements, ranging from seasonal cover for deer, elk, and many predators to year-round habitat for many small mammal and bird species. The specific benefits of forest habitat to each of these groups will be discussed in the accounts of the individual species later in this chapter. The most detailed account occurs in the section on small birds.

Several forest management recommendations aimed at enhancing wildlife values are listed below:

1. Leave as much undisturbed habitat as possible, particularly old trees and species that are difficult to restore (aspen, pinyon, juniper, and cottonwood). Not only will these trees provide immediate wildlife habitat but they will also act as sources of seed for the reclaimed land.

2. Plant mixed species, because they will provide more habitat diversity than single-species plantings.

3. Leave some old trees in place and cut trees selectively to encourage mixed-age forests.

4. Maintain 50 to 75 percent canopy cover. If more light penetration is required, thin the canopy layer selectively and avoid disturbing existing understory.

5. Do all thinning and cutting in the fall or winter to avoid disturbing nesting species.

6. Plant edges of reforested areas in a variety of shrubs and forbs to create additional cover and diversity.

Many forest management practices, including the ones mentioned, can be used to improve undisturbed forest habitat adjacent to a proposed mine site. If extensive forest management activities are anticipated, they should be coordinated with local wildlife managers and forest management specialists.

Riparian Wildlife Habitat

There is perhaps no other example in this region which demonstrates more clearly the dependency of wildlife on a particular and unique habitat type than that which occurs in the riparian communities.

Most riparian habitats occur as narrow bands of vegetation associated with marshlands and permanent or intermittent watercourses. Because of the presence of surface water, these communities generally contain a greater floral and faunal species diversity than the surrounding, more xeric habitats commonly found in this region. Consequently, many wildlife species which occur in this region do so only because of the presence of riparian habitat. Riparian habitat is important not only to the wildlife species restricted to this zone, but also to many other species which visit the area for drinking water or to prey on other species. Because some members of the riparian community, particularly the amphibians, depend on the free water and the emergent and submergent vegetation as well as the adjacent terrestrial habitat for certain aspects of their life cycle, the remaining discussion will deal with the water as well as the band of surrounding vegetation.

The following publications provide a good description of the biotic components of the marshes and riparian habitat in the NRMGPR:

Johnson, R.R. and J.F. McCormick (tech. coor.). 1978. Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Proc. Symp. USDA For. Ser. Gen. Tech. Rpt. WO-12. 410 p.

Johnson, R.R. and J.F. McCormick, and D.A. Jones (tech. coord.). 1977. Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Ser. Gen. Tech. Rpt. RM-43. 217 p.

Olson, R.A. 1980. Reclaiming Riparian Wildlife Habitat at Post-mining Spoil Impoundments.

Moore, R. and T. Mills. 1977. An Environmental Guide to Western Surface Mining. Part Two: Impacts, Mitigation and Monitoring. Chapt. II. USDI FWS/OBS-78/04.

Hopper, R.M. 1968. Wetlands of Colorado. Dept. Game, Fish and Parks. Tech. Pub. No. 22. 89 p.

USDI FWS/OBS-80/55. 1980. Streamside Areas: Management Dividends. 10 p.

Wyo. Game and Fish Dept. 1976. Considerations for Wildlife in Industrial Development and Reclamation. p. 1-17. Cheyenne, Wyoming.

The unique feature of riparian areas is the presence of surface water, either standing (lentic) or flowing (lotic). Any activity which eliminates or reduces the quality of this water will adversely affect the remainder of the community, including the wildlife species that frequent the site. Beyond the fresh water, other physical features which make the riparian areas productive include large areas of shallow water (less than 1 m deep), gradually-sloped basin walls, and naturally occurring late summer draw-down periods (Olson 1980). FWS/OBS-78/04 details the "...impacts [and] existing stipulations intended to mitigate impacts to fish and wildlife [in riparian areas] during the entire mining program."

Proposed impoundments should be viewed in relation to their surroundings. Their size should be determined by the amount of water available to fill and maintain them. Large impoundments can have adverse effects on the surrounding water table, surface water flow, and the quality and availability of downstream water. Minimum streamflow provisions for all permanent streams affected by the impoundment and other mining operations should be made. These concerns can only be addressed with the aid of a hydrologist.

The depth of the impoundment will be determined in part by the amount of water available. But, for impoundments expected to support a fish population, the average depth should be at least 4.5 to 5 m (12 ft) with areas as deep as 6 to 7 m (20 to 23 ft). These depths are necessary to avoid winter freezeout. For more details concerning fisheries habitat requirements, consult the State fisheries biologists.

The following physical changes can occur in surface water as a result of mining operations. These can seriously degrade water quality and result in lost wildlife habitat.

Changes in water chemistry can occur from an inflow of toxic materials. In severe situations, this can prove fatal to wildlife using the water for drinking; in less extreme situations, the chemical changes can make the environment unsuitable for invertebrates (which may provide an essential food source for vertebrates), fish, and for the egg and larva stages (completely dependent upon the aquatic environment for survival) of amphibians. Changes in water chemistry can also influence wetland plant establishment, species composition, and growth.

Ultimately, water quality must meet the standards set by State and Federal agencies.

Increases in water turbidity will decrease the amount of light reaching submergent vegetation and thus hinder photosynthesis. Turbidity can change water temperature and decrease the oxygen content, adversely affecting the wildlife components of the system. Turbidity can be inorganic (clay and silt particles originating from uncontrolled runoff from exposed spoil banks and unseeded areas, and fugitive dust from uncovered conveyor belts and gravel roads) or organic (phytoplankton and decaying organic matter). Moderate amounts of phytoplankton may be beneficial to the aquatic system in that they provide a source of food for higher organisms. However, excessive phytoplankton accumulations can cause a reduction in the oxygen content of the water when they decompose. Decaying organic matter poses the same problem to the system.

Increases in (inorganic) siltation can have an adverse impact on the aquatic system. In standing water, it can suffocate the eggs and larvae of many aquatic organisms. Fast rates of sedimentation can result in a shifting substrate, which hinders the anchoring of wetland plants, and excessive deposition can even fill impoundments. Small amounts of silt deposition on otherwise rocky bottoms can, however, provide a substrate for plant growth. This may be undesirable from a fisheries standpoint but beneficial for other riparian community concerns.

Erratic dewatering and flooding can have a severe impact on riparian systems. Excessive flooding can kill emergent vegetation, increase silt deposition by eroding adjacent land and flooding adjacent terrestrial habitat, and destroy terrestrial organisms. Excessive dewatering can dry out submergent vegetation. It can have a similar impact on invertebrates and the eggs and larval forms of many organisms.

A normal seasonal rise (spring) and drawdown (late summer and early fall) can be beneficial to the riparian community. Spring flooding can actually increase the size of the riparian community, while a late summer exposure of the mud flats can speed up decomposition of organic matter and recycling of nutrients into the system for future plant utilization. It can also aid in establishment of many wetland plant species by providing a moist seedbed (Olson 1980).

The U.S. Environmental Protection Agency (1977) lists 17 principles to consider in the selection and design of pollution prevention measures and control structures. Moore and Mills (1977) list numerous additional water quality stipulations for surface mine leases. Additional recommendations not mentioned in these publications are listed below:

1. If perennial waterways and impoundments are part of the reclamation plan, then 60-meter-wide buffer strips should be managed as riparian habitat on both sides of the channel. If the topography near the site is steep, the riparian habitat should extend to where the ground level first rises 1 m above the high water line.

2. Impoundments should be upstream from spoils areas but should not drain through spoils sites. Impoundments should have irregular shorelines and should not be so large that they will not fill with the amount of water available.

3. Revegetation of the shorelines should be accomplished as soon as possible after the completion of the earth work. Plant composition should include a variety of native grasses, sedges, forbs, shrubs, and trees.

4. The ratio of emergent vegetation to open water should range from 50:50 to 65:35 to provide optimum habitat for wetland bird species.

5. To provide an adequate zone of emergent vegetation along pond shorelines, contouring should not exceed a slope of 4:1 (horizontal to vertical).

6. Contouring along streams should provide slopes of no greater than 45 degrees to minimize erosion and to provide for sportsman and wildlife access.

7. Installation of weirs or other water control devices on impoundments will permit manipulation of water levels to create mud flats.

8. Fencing around impoundments may be necessary to keep cattle from overgrazing riparian vegetation, trampling mud flats and causing erosion and sedimentation. A small section of the run-off channel (or shoreline) may be left unfenced to permit access to the water for cattle and wildlife.

9. Some species of wildlife require the riparian zone to be made up of short grasses. Consequently, if the riparian zone is large, portions may be left unfenced and open for grazing. This should result in shorter and thinner riparian vegetative cover.

10. To insure successful reproduction of nesting shorebirds and waterfowl, human access may have to be prohibited during the nesting season.

11. State fisheries biologists should be consulted if any impoundments or streams are expected to support a fisheries program.

Individual Species Considerations

This section will present ways of mitigating the impacts of surface mining on certain species of wildlife. Before any mitigation or enhancement activities take place, it is important to know the type and degree of impact which the biotic resources will experience. Chapter III and IV of USDI FWS/OBS-78/04(1977) describes in detail the potential effects of all phases of surface mining on the fish and wildlife resources.

Generally, the impacts fall into one of two categories: First, the species with low mobility (most amphibians, reptiles, and small mammals) will usually be eliminated as soon as the vegetation and soil is removed. The more mobile species (most birds, predatory mammals, furbearers, and larger mammals) will move to adjacent areas as soon as their habitat is disturbed. Although these individuals are not immediately eliminated, their appearance on adjacent habitat will usually increase competition with the residents. This will lead to overuse and deterioration of the habitat. Increased competition may also lead to increased vulnerability to diseases and predation. All of these circumstances lead to an eventual decline in the population. In other words, animals cannot ordinarily move to another area and carry on their existence as if nothing happened. In most locations, the other areas are already occupied.

The resource manager can respond to these potential impacts in one of two ways: First, measures can be taken during the mining process to lessen the immediate impact and second, enhancement procedures can be implemented during the reclamation process to reestablish wildlife populations to their pre-mining levels.

The scope of the reclamation effort will become apparent at the conclusion of the pre-mining inventories. Once the affected species are identified, the choice of reclamation and enhancement techniques must be made and written into the plan.

Amphibians and Reptiles

Amphibians (salamanders, frogs, and toads) and reptiles (turtles, lizards, and snakes) are often ignored in widlife management plans. With the current public interest in non-game species and the holistic approach to resource management, these species can no longer be ignored. Ecologically, the amphibians and reptiles represent a food source for many fish, birds, and mammals. Lizards, frogs, and toads help control insect populations while snakes prey heavily on rodents and become prey for other predators.

The following publications will provide the manager with references for this group:

Stebbins, R.C. 1966. A Field Guide to Western Reptiles and Amphibians. Houghton Mifflin Co. Boston. 279 p.

Baxter. G.T. and M.D. Stone. 1980. Amphibians and Reptiles of Wyoming. Wyo. Game and Fish Dept. Bull. No. 16. 137 p.

Bernard, S.R. and K.F. Brown. 1978. Distribution of Mammals, Reptiles and Amphibians by BLM Physiographic Region and A.W. Kuchler's Associations for the Eleven Western States. USDI BLM T/N 301. 169 p.

Amphibians are moist-skinned vertebrates which spend part or all of their life cycle in water (eggs, larvae, and adults) and part on land (adults). They are restricted to moist or sheltered habitats, often burrowing into moist soils during the hot days of summer. The riparian community with its adjacent open water provides amphibians with all of their habitat requirement. Adults of some species often travel far from open water to feed but always return to shallow water (critical habitat) to breed and hibernate. Ephemeral streams and springs as well as permanent standing and flowing water all serve as habitat for amphibians native to this region (Baxter 1980).

The reptiles are primarily terrestrial; their preferred habitat consists of loose and sandy soils, rocky areas, and areas of diverse topographic features. Their scaly bodies provide a relatively water-tight skin, enabling them to exist in arid and semiarid environments.

Because of the low mobility of these groups, they are eliminated by any activity that removes vegetation and soil. Little can be done to avoid this loss. Therefore, the mitigation efforts must focus on restoring and enhancing the habitat during the reclamation period.

The following measures should be a part of the reclamation plan:

Amphibians

1. Riparian communities and fresh surface water represent the preferred and critical habitat for these species. The primary objective for the reclamation and enhancement plans for amphibians will be the restoration of wetlands and riparian habitats as outlined in the section on riparian habitat.

2. Riparian habitat should be located in sites with uninterrupted migration corridors to undisturbed riparian zones. This will facilitate the natural repopulation of the new sites and will encourage long-term genetic mixing and the dispersal of excess individuals.

3. Where riparian habitat exists as isolated ponds or marshes, the repopulation effort may require a transplant program whereby eggs from nearby similar habitat are introduced to the new site. This should not occur until adequate habitat conditions exist at the new site. When handling eggs, care should be taken not to shock them with sudden changes in water temperature and chemistry.

4. Any transplant program should be coordinated with local wildlife managers.

Reptiles

1. When suitable habitat is available, most native reptiles will repopulate the reclaimed site naturally.

2. Topographic diversity is a key element in preferred reptile habitat. This includes rock piles, rock outcrops, and shrubby areas. Stable mine-end high walls facing south, southwest, and southeast with a zone of loose debris along the base can provide prime reptile habitat.

3. Diverse and abundant prey populations are essential for supporting reptile populations and these can be achieved with habitat diversity.

Birds

There are many references dealing with the ecology, behavior, and habitat management of North American birds. The following set, although somewhat old, provides a thorough account of all bird species; their historic distribution, habitat affinities, and other basic natural history information:

Bent, A.C. 1919-1968. Life Histories of North American Birds. U.S. Nat. Museum. Wash. D.C. and: Dover Publishing, Inc. New York. 20 vols.

The following publication is the most useful, up-to-date encyclopedia of North American Birds. It covers basic natural history data and includes an excellent reference section:

Terres, J.K. 1980. The Audubon Society Encyclopedia of North American Birds. Alfred A. Knopf, Inc. New York. 1,110 p.

Small Birds

This category includes all species except the game birds, raptors, shorebirds and waterfowl. This group has received little attention in past management and rehabilitation efforts. Most of the older literature consists of ecological descriptions of small bird habitat with few accounts of actual habitat improvement procedures.

Interest in non-game bird management has increased in recent years and has resulted in several symposia. The resulting publications are listed below:

USDA Forest Service. 1975. Proceedings of the Symposium on Management of Forest and Range Habitats for Non-game Birds. USDA For. Ser. Gen. Tech. Rept. WO-1. 343 p.

USDA Forest Service. 1977. Non-game Bird Habitat Management in the Coniferous Forests of the Western United States. USDA For. Serv. Gen. Tech. Rept. PNW-64.

USDA Forest Service. 1979. Management of North Central and Northeastern Forests for Non-game Birds. USDA For. Serv. Gen. Tech. Rept. NC-51. 268 p.

USDA Forest Service. 1980. Management of Wesern Forests and Grasslands for Non-game Birds. USDA For. Serv. Gen. Tech. Rept. INT-86. 535 p.

Because of their relatively high mobility, most small bird species are likely to repopulate an area once suitable habitat exists. And because of their specific habitat requirements, the key factor in attracting these species to a reclaimed site is the rapid introduction of all required habitat features. The pre-mining inventory, including the inventory of similar adjacent habitat, will provide the best direction for the reclamation plan.

One factor to consider when reclaiming small bird habitat is the overall size of the site. Most small birds maintain exclusive territories from which other individuals of the same species (other than their mate and dependent offspring) are driven away. This results in a spacing of pairs and ultimately a natural limit to their own numbers.

As obvious as it is that territoriality limits species density (Brown 1969; Chitty 1967; Hine 1956), it is also obvious that more than one breeding pair on an isolated tract of land is required to maintain a viable, self-perpetuating population. The long-term vitality of the population requires a large gene pool from which new individuals can be recruited and from which genetic variability can be maintained. If the habitat can maintain only a few breeding pairs, the likelihood of genetic isolation and localized extinction is greatly increased (Verner 1975). This problem can be compounded if the distance between similar habitats is sufficiently great to restrict the movements of individuals from one population to another.

Considerable attention has been paid in recent years to this subject, referred to as island geography (Verner 1975; Faaborg 1979; Wilson and Willis 1975; Whitmore 1980; Samson 1980). However, little information is currently available clearly defining the minimum number of individuals required to maintain a population or defining how isolated a small population may be and still retain enough genetic exchange to maintain its viability. Welty (1962) and USDA Forest Service (1980) provide additional comments on this subject.

However perplexing the problem, the best procedure is to thoroughly inventory all adjacent habitat and plan to reclaim the disturbed mine site to a condition similar to adjacent habitat. This will ensure that islands of completely dissimilar (and unnatural) habitat will not be created.

Some management guidelines are listed below. Additional and more specific information is available in USDA Forest Service (1975), USDA Forest Service (1979), and USDA Forest Service (1977).

1. Unless critical species are involved, address the entire ecosystem and avoid single-species management programs.

2. Concentrate reclamation and enhancement efforts on riparian areas to maximize habitat diversity. This will benefit the greatest number of bird species.

3. Outside of riparian areas, maximize habitat diversity by increasing topographic and plant species diversity.

4. To insure repopulation by native birds, stress the replacement of lost ecological components.

5. Include sagebrush in grazing lands and avoid monocultures, particularly pure seedings of crested wheatgrass.

6. Emphasize native plants along edges, fencerows, drainages, and odd corners in crop lands. Include annuals, perennials, forbs and shrubs. The latter, especially, adds habitat diversity.

7. Leave unharvested strips along wild habitat in agricultural crop lands to supply small birds with food.

8. Include as great a variety of native grasses and forbs as possible beyond the range of sagebrush in grazing land to provide additional habitat diversity.

9. Where necessary prohibit grazing until the vegetation is established. Future control of grazing will affect plant species composition and form; heavy grazing will yield shorter and thinner cover, whereas light grazing will result in thicker and taller cover. Each regime will accommodate different species of birds.

10. Encourage planting of ecologically appropriate trees. If a forest community is planned, several species should be planted. Dead snags will provide valuable perching sites for birds.

Many forest management procedures will benefit small birds. Any old trees or dead snags left standing will greatly increase bird species diversity and population densities. Mature and dead trees provide nesting sites for a variety of birds (woodpeckers, blue birds, chickadees, wrens, and swallows) which would otherwise not occur in the area (Scott and Patton 1975). (Absence of adequate nesting sites becomes the limiting factor in the life cycles of these species).

Guidelines for managing forest lands for the benefit of birds can be found in the forest habitat and wildlife section of this chapter.

The addition of man-made features to the reclaimed site can benefit many species of small birds. The most common is the nest box. These have proven successful in attracting at least 48 species of small birds (Terres 1980, p. 69). The first priority, of course, should be to maintain or supply natural features. Wildlife populations have evolved in the natural environment and this procedure has apparently served them well (Graul 1980). Relying on man-made features will only tie future survival more closely to continued maintenance and management.

Nest box design criteria are provided by Terres (1980, p. 69).

Shorebirds

Shorebirds occur in three major management groups in the NRMGPR. The most numerous are those which occur only briefly as seasonal migrants. The second group includes those which feed in the shallow waters and mudflats but nest in upland habitats. Members of the third group feed in shallow water and on mud flats, and nest near the water's edge where little or no cover occurs.

As with most species, the successful occurrence of shorebirds depends on the long-term availability and quality of critical habitat. For shorebirds, this means wetlands and riparian habitats. Research on wetlands management has been occurring for decades. Sanderson and Bellrose (1969) and Bellrose and Low (1978) provide a review of these efforts and Johnson and Jones (1977) present the proceedings of a symposium on the importance, preservation, and management of riparian habitat. These works present an overview of wetlands management, the key to shorebird management. Additional information on wetlands management can be found in this chapter under the heading: riparian wildlife habitat.

The following publication provides the best source of information on the management of shorebirds and their habitat:

Sanderson, G.C. (ed.). 1977. Management of Migratory Shore and Upland Game Birds in North America. Inter. Assoc. Fish and Wildl. Agencies. Wash. D.C.

Waterfowl

Because of the tremendous popularity of waterfowl, perhaps more is known about their management than any other group. Each State wildlife management agency has a staff of waterfowl biologists who have formulated detailed management objectives and procedures. Whenever waterfowl habitat is included in a reclamation plan, the effort should be closely coordinated with these agencies.

The protection of migratory waterfowl and their habitat is jointly shared between the State wildlife agencies and the U.S. Fish and Wildlife Service. Both agencies should be notified whenever a proposed mining activity occurs on or near major waterfowl habitat.

Numerous publications outline techniques commonly used to manage waterfowl habitat. Some of these are listed below:

Giles, R.H. 1969. Wildlife Management Techniques. The Wildlife Soc. Wash. D.C. p. 211-223.

Atlantic Waterfowl Council. 1963. Waterfowl Habitat Development and Management Techniques Handbook. Atlantic Waterfowl Conf.

Trippensee, R.E. 1948. Wildlife Management: Fur Bearers, Waterfowl, and Fish. McGraw-Hill Book Co. Vol. II. 572 p.

Hooper, R.M. 1968. Wetlands of Colorado. Colo. Game, Fish and Parks Dept. Tech. Pub. No. 22.

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Since waterfowl management is closely tied to wetlands and riparian habitat management, it is imperative that the reclamation effort consider the entire watershed. The quality, quantity, and accessibility of water is often the key element in the management of all biotic resources of the semiarid NRMGPR. Consequently, the proper management of water can have far reaching significance in the overall success of the reclamation effort.

When the pre-mining inventory is completed, the following questions should be addressed:

> Is existing waterfowl habitat going to be completely eliminated, partially eliminated, or only disturbed by the mining operation?
>
> What size and type (deep impoundment, shallow marsh, or flowing water) or waterfowl habitat is involved?
>
> What is the relative location of the disturbed habitat to the nearest similar existing habitat?
>
> What size and type of aquatic habitat can be furnished via the reclamation effort?
>
> What species, other than waterfowl, will utilize this habitat?

In answering these questions, the following points must be considered:

More migrating waterfowl will be attracted to a new area if it is close to existing high concentrations of waterfowl. Expected waterfowl use can be predicted by assessing nearby waterfowl use.

Impoundments meant for waterfowl can vary in depth depending on the species expected at the site. Diving ducks can utilize water 4.5 m (12 ft) deep but light penetration beyond that point is usually so restricted that little plant growth occurs.

For dabbling ducks and geese, water depths should not exceed 45 cm (18 in). For optimum plant growth, average depth should not exceed 75 to 90 cm (30 to 36 in). Emergent vegetation should cover no more than 35 to 50 percent of the impoundment (Wyo. Game and Fish 1976; Olson 1980). Therefore, no more than 35 to 50 percent of the impoundment should be less than 75 to 90 cm deep and the shallow areas should occur in irregular patterns.

Water depth may be manipulated with control structures at the discharge point. These devices can be used to control vegetative growth in the impoundment by varying the amount and timing of mudflat exposure. Water fluctuations should be controlled if naturally severe. High water should be maintained early in the spring before waterfowl nesting begins, thus forcing nesting to occur above any later flooding.

Shorelines and associated shallow water are important elements of waterfowl habitat. The amount of shoreline can be increased by constructing peninsulas and coves. These should be oriented to provide maximum protection from prevailing winds.

To reduce shoreline slumping and erosion from wave action, shoreline slopes should not exceed 45 degrees. For optimum waterfowl value, slopes should not exceed a 5:1 ratio of horizontal distance to vertical.

Islands provide additional shoreline and areas for nesting and loafing. They should be at least 3 m (10 ft) in diameter and 60 to 90 cm (2 to 3 ft) above the high-water line. They should be placed in water at least 60 to 120 cm (2 to 4 ft) deep.

Islands should have their windward shoreline protected with gravel or rocks to withstand wave action. Island shorelines should have a minimum 3:1 slope.

On large bodies of water, islands should be about 90 m (100 ft) apart, or 1 per 4 acres.

Three types of vegetation will be considered: shoreline, (including islands), submergent, and emergent.

Shoreline or riparian vegetation should be established as soon as possible to stabilize the soil and prevent erosion and sedimentation. Equally important, shoreline vegetation provides preferred nesting habitat for many species of waterfowl. For additional information on shoreline management, see the section on riparian wildlife habitat.

Listed below are recommendations for managing wetlands vegetation to enhance waterfowl populations:

Mixtures of native sedges, grasses, forbs, shrubs, and trees should be used. The choice should be made based on ecological compatibility and the ultimate management goal.

For example, willows may be excellent for stabilizing shorelines but may be detrimental to geese if the shoreline is to provide them with a grazing site.

If geese are expected to use the site, extensive grassy areas should surround the impoundment. These will provide the nesting geese with essential feeding areas.

Shoreline vegetation will have to be protected from excessive grazing. The amount of grazing will determine overall shoreline stability and eventual plant species composition and form.

Maintenance and reconstruction of shoreline habitat is of critical importance to water foul population in the northern great plains (photo--Wyoming Game and Fish Department, Cheyenne, Wyoming)

Elk and many other species have critical habitat requirements. The success of such species is dependent upon meeting these requirements although they may occur for only short periods of time. Populations cannot be maintained for extended periods which exceed the carrying capacity of the land. (photo--Wyoming Game and Fish Department, Cheyenne, Wyoming)

Low-growing plant species responding well to this region are: foxtail barley, prairie cordgrass, sedges, and rushes. Rushes exist as transition species between the terrestrial communities and the open water.

Brushy or woody species which adapt well to this region are: willow, dogwood, wild rose, serviceberry, chokecherry, currant, gooseberry, and sagebrush.

Tree species well adapted to this region include cottonwood, aspen, alder, birch, wild plum, boxelder, and ash.

Emergent vegetation--those species rooted in water and growing above the water surface--provide necessary escape and brood-rearing cover for most waterfowl species.

Major emergent species are: cattails, rushes, and bulrushes. Bulrush seeds are an important waterfowl food.

Emergent species can be controlled by manipulating water levels. Raising the water level will kill cattails and most other emergent species. Late summer drawdowns will expose mudflats and increase seed germination and the decay of organic matter.

Bulrushes can be planted from tubers in late summer in 10 to 15 cm (4 to 6 in) of mud, 30 to 45 cm (12 to 18 in) apart.

Cattails and rushes will revegetate from seeds in mid- to late-summer on exposed mudflats. The mudflats can be exposed naturally or by managed drawdowns. The mudflats should remain moist and not be allowed to dry out.

Submergent plants--those species rooted and growing entirely under water--are best served with stable water levels. If drawdowns are required, they should occur in late summer.

Whenever possible, water levels should be raised in early fall to benefit migratory waterfowl.

Waterfowl nest sites in riparian habitat can be enhanced with proper management. Several procedures are listed below:

Islands and peninsulas constructed for use as nest sites should be planted with sedges or grasses. If conditions do not support plant growth, placement of small logs and/or driftwood on the sites will provide some cover and protection from the wind.

Artificial nesting platforms are readily used by geese. Giles (1969, p. 211-213) provides designs for these structures. They should be a minimum of 75 cm (30 in) above the high water line but can be as high as 2 m (6.5 ft). They should be a minimum of 1.5 m (60 in.) in diameter.

Surface mining operations and support activities should be planned and operated with minimum impact on nearby waterfowl habitat. In addition, certain non-mining activities may have to be regulated. Listed below are several recommendations which will enhance waterfowl habitat and reproduction:

A 90- to 150-m (300- to 500-ft) buffer zone of undisturbed habitat should be left around all waterfowl habitat.

Water crossings should be avoided if possible, and unavoidable crossings should be planned to minimize stream disturbance.

Power transmission lines should not cross open water or be located close to important flyways (between nesting, feeding, and roosting areas).

Human access to waterfowl areas should be curtailed or denied during the nesting season.

Hunting should be restricted until the population has established itself; if the area is small, hunting may have to be limited to only one or two days a week to keep from chasing all waterfowl from the area.

Upland Game Birds

Game birds commonly encountered in different areas of the NRMGPR are sage grouse, ruffed grouse, blue grouse, spruce grouse, prairie chickens, sharp-tailed grouse, wild turkey, chukar partridge, mourning dove, and ring-necked pheasants. The mourning dove is the only migratory species in this group and comes under the jurisdiction of the U.S. Fish and Wildlife Service through the Migratory Bird Treaty Act (16 U.S.C. 701-718h).

Because of the economic importance of these species, most State wildlife agencies already have management objectives and programs in operation. Consequently, these agencies should be contacted and all reclamation decisions should be made with their cooperation and understanding.

The following references provide broad coverage of this group of birds:

Hjorth, I. 1970. Reproductive Behavior in Tetraonidae. Viltrevy: Swedish Wildlife. Vol. 7. No. 4. 412 p.

Johnsgard, P. 1973. Grouse and Quails of North America. Univ. Nebraska Press.

Bent, A.C. 1932. Life Histories of North American Gallinaceous Birds. U.S. Nat. Mus. Bull. No. 162.

Sage Grouse. Historically, sage grouse occurred throughout the sagebrush/ grasslands of the West. Numerous studies have proven the importance of sagebrush as food and cover for young and adult sage grouse (Rogers 1964, FWS/OBS 1978, Call 1979a, and Patterson 1952).

As with most species, the primary impact of surface mining on sage grouse is loss of habitat, including strutting grounds (leks), nesting cover, summer forage habitat, and winter range. Preferred sage grouse habitat occurs in the mountain foothills and along the fertile sagebrush-covered flats bordering mountain streams (Call 1979a). Sage grouse food and cover requirements have been determined by a number of investigators (FWS/OBS 1978, Call 1979a, Patterson 1952, Rogers 1964). Optimum sagebrush densities vary with sage grouse age and sex classes. These range from stands with openings from 0.1 acre to 10 acres in size to stands of up to 50 percent sagebrush canopy cover (Table 2).

TABLE 2. SAGE GROUSE HABITAT REQUIREMENTS (FROM: CALL 1979a AND OTHERS).

Age/Sex	Sagebrush Cover (%)	Food Consumed
Adult males	20-52% canopy	Sagebrush (year-round) Forbs (summer only)
Adult hens (nesting)	15-35% canopy	Sagebrush (year-round) Forbs (summer only)
Juveniles (broods)	1-20% canopy	1st week, insects 1-11 weeks, forbs 11 weeks-, sagebrush
All sage grouse (winter)	20% or greater canopy, always taller than snow depth	Sagebrush leaves

Like many species, the sage grouse is capable of covering a large area in its yearly search for appropriate habitat. It is not uncommon for grouse summering in high intermountain valleys to migrate as much as 32 km (20 mi) to lower and more suitable winter habitat. In other locations, the year-long habitat requirements may be met within a 1.5- to 3-km^2 (1-to 2-mi^2) area. The first step in initiating a reclamation plan for sage grouse is to determine what segment or segments of their habitat is being disrupted.

Winter feeding patterns indicate nearly a 100 percent dependency on sagebrush leaves. In all areas, the sagebrush must extend above snow level to be available to sage grouse. Black sage appears to be the preferred species (Pyrah 1954, Crawford 1960), but if this low-growing species becomes covered with snow, the sage grouse will move into areas of taller sage.

Of all the habitat elements, winter range is usually in shortest supply. Traditionally, the best (most used) wintering areas were the lowland, gently sloping valleys with abundant medium to tall sagebrush. Unfortunately, many of these areas have been converted to agricultural lands by having the sage thinned or completely removed.

The mere presence of extensive stands of sagebrush does not assure its availability during the critical winter season. In many areas, snow depth may exceed sage height, making it unavailable to the sage grouse. This condition may not occur every winter or all winter, but if it happens only once every few years and only for a few days or weeks, the sage grouse population will suffer.

Surface water is thought by some biologists to be a critical component of sage grouse summer habitat. When precipitation stimulates the growth of succulent forbs and grasses, grouse can obtain adequate metabolic moisture by eating these plants. They can also obtain moisture from early morning dew accumulations.

Greatest sage grouse densities usually prevail in areas where surface water is available every 2 to 4 km (1 to 2.5 mi) for the duration of the summer and fall. Snow supplies winter water requirements.

Sage grouse habitat reclamation programs will vary with the desired goals; different habitat elements require different procedures. Some guidelines are listed below:

Big sagebrush plantings are best accomplished by using containerized stock. Densities of approximately 800 to 900 plants per acre appear to provide optimum food and cover conditions. Inclusion of bitterbrush in the planting (not to exceed a 1:10 ratio) can provide additional nesting cover as well as food for other wildlife species.

The loss of habitat can be partially mitigated if adjacent undisturbed habitat can be improved for sage grouse. This may include thinning existing areas to increase openings or initiating sagebrush plantings if densities are thinner than desired. Any substantial alteration of sagebrush stands outside the mine area should be coordinated with State wildlife biologists.

Details of sagebrush control procedures are provided in Call (1979a).

A problem often encountered in coal surface mining operations is the destruction or disturbance of sage grouse strutting grounds (leks). Leks are traditional mating grounds which in some cases have been used for decades (Patterson 1952). Both males and females tend to return to the same leks year after year, although seasonal exchanges with nearby "satellite" leks occur quite regularly. Satellite leks may be from 0.4 to 7.5 km (0.25 to 4.5 mi) from the main lek (Tate et al. 1979, Hjorth 1970).

Breeding activity begins as early as mid-March on the more southerly grounds and continues for two months. The birds arrive on the leks before daylight and remain until 2 or 3 hours after sunrise. If the birds are chased from the lek, they will usually not return again until late afternoon or the next day. If this disturbance becomes a daily occurrence, the birds may abandon the lek. Fortunately, occasional disturbance has little adverse effect on the population because the breeding season is long and females remain receptive for several days.

Studies have indicated that most females nest within a 1.3-km radius (2 mi) of the lek they visit (Wallestad and Pyrah 1974, Wallestad 1975). Leks are often located at a point intermediate between winter and summer range (Call 1979a) and usually within openings in the sagebrush. These openings range in size from 0.1 acre to 10 acres and are occasionally as large as 100 acres. Leks usually occupy areas of low snow accumulation and early melt-off. They may contain short, sparse sagebrush growth or none at all. Grassy swales, natural shortgrass meadows, or irrigated meadows where the grass is kept short can all be used as leks. Completely denuded areas can also serve as strutting grounds.

Males defend an area ranging in size from 5 to 15 square meters (Johnsgard 1973) to over 250 square meters (Hjorth 1970). Males tend to concentrate around a given area within the lek, rendering grouse densities meaningless.

Sage grouse frequently become accustomed to nearby roads and traffic (in some cases as close as a few meters away). This phenomenon appears to be related to uniform and predictable traffic patterns--i.e., a constant or even flow of traffic distracts birds less than erratic traffic patterns and vehicles which stop beside the birds.

When a lek is scheduled for destruction by a proposed mine, certain steps can be taken to mitigate this loss. Tate et al. (1979) and Eng et al. (1979) both report varying degrees of success in relocating birds to satellite and man-made leks 1.5 and 3.2 km (1 to 2 mi) away, respectively.

The following procedures should be followed before any attempt is made to move birds from one lek to another:

All sage grouse habitat should be mapped, emphasizing sagebrush density, height, and percent canopy cover.

All existing leks and satellite leks should be located and mapped. The number of both male and female sage grouse using the lek should be determined.

All nesting and potential nesting areas should be mapped (the latter based on a 15 to 35 percent canopy cover).

Brooding areas should be mapped based on flushing transects and preferred habitat (2 to 20 percent canopy cover)(June).

All wintering areas should be mapped based on ground and aerial surveys (February and March).

With the results of the survey, the manager will have to assess the kind and amount of disturbance the sage grouse will experience with the mining operation. This assessment will have to take into account the geographic relationship of all the components of the sage grouse habitat as well as the locations of mine activity. With this information, the following points should be considered:

If a lek is to be destroyed and a satellite lek exists as close to the other habitat components as did the original lek, then the mitigation effort should be directed toward relocating the birds to the satellite lek.

Modifications of the satellite lek may have to be made. This may include the removal of some sagebrush and increasing its size to at least equal that of the destroyed lek.

Cover modifications should be completed in mid-summer to allow late summer grass and forb growth, thus reducing the danger of erosion. If the modifications cannot be made in late summer, they should occur during the winter when the ground is frozen and a tractor blade can be used to remove the vegetation with little damage to the soil.

If a new lek must be established, the site should resemble the destroyed lek in as many aspects as possible, including vegetative cover, aspect, and slope.

The new lek should be located between the summer and winter range and within 3.2 km (2 mi) of the nesting areas. Nesting densities range from one nest per acre (Patterson 1952) to one nest per 65 acres (Klebenow 1970). By knowing the number of females in the population, it can be determined if sufficient nesting habitat exists within the area.

Leks should be located near surface water. Distances between water sources should not exceed 4.8 km (3 mi).

The relocation of sage grouse to satellite or new leks may require additional effort. Listed below are techniques used by Tate et al. (1979) and Eng et al. (1979) to successfully move birds to new sites:

Place painted silhouette decoys of sage grouse on the lek in early or mid-March to simulate a mating center.

Place a battery-powered cassette auto-reverse tape player at the edge of the lek (camouflaged) with two speakers spread 6 to 15 m (20 to 50 ft) apart.

Obtain a cassette tape with sounds of an active sage grouse lek recorded on both sides and place it in the recorder.

Install a 24-hour self-timer to start the system each day about one-half hour before sunrise and to shut off 3 to 4 hours later.

The system may also be set to activate 2 hours before sunset, since active leks are frequently visited both in the morning and afternoon.

The system should be reset every 10 to 14 days to compensate for the longer days.

Observations should be made at least every 4 days to check the equipment and to evaluate the results.

There are three species of woodland grouse which may be encountered in the NRMGPR: the ruffed grouse, blue grouse, and spruce grouse. These species all depend upon forest habitat for their survival. Two options exist which will help mitigate the adverse impact mining may have on these birds. First, enhancement of non-disturbed habitat and second, reclamation of the disturbed land to again support these species.

Because of the nature of the habitat, the reclamation effort will necessitate a long-term commitment and can be accomplished only with the understanding of the seral stages required to achieve the desired goal: a forest ecosystem.

All three species are sufficiently mobile that once adequate habitat is provided, they can be expected to repopulate the site naturally.

The woodland grouse species are solitary through much of their life cycle. They will, however, on occasion join together in temporary winter flocks. They are non-lek forming with individual males spread widely throughout their habitat. Most of these birds do not migrate, or migrate only short distances, rarely more than 3.3 to 6.6 km (3 to 4 mi), and then usually in association with a substantial altitude change.

Ruffed grouse. Ruffed grouse have the greatest range of all North American grouse. In the NRMGPR they prefer deciduous or mixed conifer-deciduous woodlands. They appear in virgin timber stands and in cutover lands, mixed hardwood forests, and riparian areas. In this region, the riparian areas represent their most important habitat.

A number of references provide habitat descriptions (Marshall 1946, Phillips 1967, Hungerford 1957, Wing 1951). The key element in grouse habitat is diversity--plant species diversity, vertical cover diversity, and interspersion of small brushy openings. Most adult birds remain year-round within a one-quarter square mile area. Dispersing young birds may travel only 1.5 to 3 km (1 to 2 mi) from their birth place (Hjorth 1970).

Male reproductive activities revolve around a "drumming log." These consist of downed logs 30 cm (12 in.) in diameter or larger. In the eastern United States, rock and stone piles are also frequently used as "drumming logs." In all cases, drumming logs are surrounded by a thick, protecting screen of low understory vegetation. An adult male may use several drumming logs during a breeding season (April to early July) and use the same log year after year. During the breeding season, male activity is usually centered within a 10-acre area (Hjorth 1970).

Habitat requirements include breeding cover, nesting cover, brood-rearing cover, and winter cover. Nesting cover is similar to drumming log cover; thick undergrowth near the edges of small clearings. Preferred brood rearing areas are characterized by brushy openings with abundant forbs and grasses. These areas provide cover as well as succulent plants and insects for the young.

Roosting cover should include coniferous trees, preferably juniper, spruce, or fir. Pines are usually too open to protect the roosting birds from winter cold and predators.

Ruffed grouse are omnivorous feeders; juveniles are insectivorous and will supplement their diet with early ripened fruits and new green shoots. Fruits and seeds as well as insects make up the bulk of the late summer diet. Winter food consists of the catkins of aspen, various willow and hardwood buds, twigs, and bark, as well as any available seeds and fruits.

Reclamation and enhancement efforts should include upgrading adjacent undisturbed habitat to support additional numbers of ruffed grouse. The objectives should be to provide habitat as described above. Riparian areas can provide excellent grouse habitat if willows and cottonwoods are encouraged. Additional management guidelines are listed below:

Provide a herbaceous understory of serviceberry, huckleberry, snowberry, chokecherry, wild rose, hawthorn, mountain ash, and gooseberries. Plantings should be in clumps, not evenly scattered. Plantings of these species should be concentrated in clearings and along forest edges.

Drumming logs can be added to appropriate habitat (dense understory of above-mentioned plants and young coniferous trees, primarily on south and southwest slopes) by falling existing trees (several per 10 acres) or by moving new logs onto the site. These should be over 30 centimeters (12 in.) in diameter and 2 to 4 m (6 to 12 ft) in length.

The canopy should be dominated by deciduous trees with some spruce, fir, or juniper interspersed to provide roosting cover.

Disturbance of drumming and nesting areas should be minimized from early April to late July.

Spruce and blue grouse. Knowledge of the habitat requirements of spruce and blue grouse is incomplete. Both species are closely associated with coniferous forests, are generally nonmigratory, solitary, and non-lek forming.

The spruce grouse rarely leaves the cover of dense spruce and nests on the ground, usually along the edges of small forest openings but in dense understory vegetation. Summer foods include huckleberries, snowberries, and new needles of spruce, fir, larch, juniper, and pine. Spruce grouse also eat insects, and buds of various hardwoods and shrubs. Openings with dense understory growth provide important summer brood-rearing areas (USDI FWS/OBS 1978).

Blue grouse tend to favor ponderosa pine and Douglas-fir forests. Brood cover must have a relatively dense herbaceous canopy (35 to 50 percent cover) tall enough to conceal the birds. Most broods spend the early summer in lower riparian areas and migrate to higher altitudes in late summer and fall. Males make this movement soon after the mating season (April to late July) and when the higher elevations become snow-free. In southwestern Montana, breeding territories of male blue grouse average nearly 7 acres and contain at least one thicket of conifers (Martinka 1972). Winter cover is provided almost exclusively by thick spruce stands.

Summer diet is made up of a variety of forbs (new growth), seeds, and berries as well as some insects (Stewart 1944). Winter food consists of the needles of fir, pine, spruce and hemlock. Winter roosting cover is provided by thick fir stands.

Reclamation efforts intended to benefit either species demand a long-term commitment to establishing the required forest components. Enhancement of undisturbed habitat can include planting understory herbaceous and shrubby species. Roosting cover can be provided by planting coniferous species and/or by "topping" some existing coniferous trees to stimulate a thick secondary growth in the mid-portion of the trees. This creates excellent, thick roosting sites.

Three other species of open-range grouse may be encountered in this region. These include the greater prairie chicken, lesser prairie chicken, and sharp-tailed grouse. All are lek-forming species and all show some degree of socialization away from the lek. All exhibit a limited amount of seasonal migration depending on climate and snow accumulation. Females may migrate farther than males. Sharp-tailed grouse inhabit grasslands interspersed with shrubs and trees, while both species of prairie chicken prefer open grasslands.

Prairie Chickens. Formerly, these species were found throughout the western prairie grasslands from southern Canada to Texas. In the NRMGPR, the lesser prairie chicken now exists only in the southeastern portion of Colorado while the greater prairie chicken can be found in limited numbers in southeastern Wyoming and eastern North and South Dakota.

Both species require extensive areas of native rangeland. The lesser prairie chicken occurs in sandy sagebrush habitat during the fall and winter but appears to prefer shortgrass areas for the remainder of the year. Lek vegetation should be short (less than 15 cm) while nesting cover should be tall and dense enough to cover the nest and female (Anderson 1969, Kirsch 1974). Nesting habitat should exist within 1.6 km (1 mi) of the lek.

Sharp-Tailed Grouse. Sharp-tailed grouse habitat requirements are intermediate between those of the prairie chickens and the forest species. They require several square miles of relatively open country interspersed with scattered shrubs and trees (Newman 1959). Their leks are situated in shortgrass areas and usually on or near low hilltops (Hamerstrom et al. 1951). Hjorth (1970) summarizes the main habitat features for the sharp-tailed grouse as follows:

> In spring and summer sharp-tailed are birds of the open country and the fringing brushlands. In later summer, they aggregate into coveys of about a dozen individuals. In autumn, these flocks move toward aspen thickets and oak woods and spend more and more time of each day there. Encouraged by hard weather in the winter months, the flocks join to form packs of fifty or more individuals (up to 400 are reported).

In the winter months, these birds spend more time in trees eating catkins and buds. Nesting usually occurs in grassy clearings (5 to 10 acres in size) which are near larger areas of brush and grassy areas (USDI FWS/OBS 1978).

The wide seasonal habitat requirements are also apparent in their food preferences. They utilize fewer seeds than do the prairie chickens and more plant material, berries, fruit and buds. In North Dakota, weed seeds and small grains appear in the fall diet along with buds and insects (Aldous 1943). More than any of the other species, male sharp-tailed grouse will appear on the leks during almost any month of the year, although breeding occurs only from April 1 to late June.

Major impact to sharp-tailed grouse occurs due to loss of leks and loss of nesting, summer, and winter habitat.

Reclamation efforts should be directed at replacing lost habitat components, with emphasis on grassland openings. Enhancement efforts should be directed to nearby undisturbed habitat. This should include providing more openings through controlled burning and/or concentrated plantings of winter browse species such as hawthorn, Russian olive, silver buffaloberry, western snowberry, wild rose, serviceberry, willow, and chokecherry. These species should be planted as dense thickets in drainages and along forest edges because these birds seldom enter heavily timbered areas (Trippensee 1948).

Wild Turkey. Wild turkeys are strongly associated with ponderosa pine, fir, and riparian habitats. The open branches of mature ponderosa pine provide favorite roosting sites. Turkeys eat a variety of foods, including the seeds and berries of the ponderosa pine and juniper (Boeker and Scott 1969). Insects, particularly grasshoppers, are eaten whenever available.

Turkeys require more space than any of the other upland game birds. Daily summer range can encompass several square miles. Important habitat elements include mature trees for roosting, food-bearing plants, free water, and dusting areas. Because of their dependency on mature trees and forest cover, the reclamation effort will have to include a long-term commitment if disturbed land is to provide turkey habitat. Also, because of the extensive land area required to maintain a population (estimates range from 1,000 to 100,000 acres), efforts to provide turkey habitat should be undertaken only if the disturbed site occurs adjacent to occupied habitat (Trippensee 1948).

Enhancement of undisturbed habitat may mitigate the losses brought about by surface mining. Measures which maintain productive turkey range conform with sound forestry practices, including limiting grazing (primarily from domestic stock) so as not to seriously reduce dense concentrations of undergrowth. Mixed-age forests provide the optimum diversity of cover. Selective cutting and construction of small openings (less than 5 acres) containing abundant understory cover can provide the desired mix of habitat elements.

Chukar Partridge. The chukar partridge is an introduced species originating from the Middle East. It inhabits the arid, open, rocky, steep, sagebrush- and grass-covered slopes of much of the West. It roosts in rough rocky areas but not in trees (Weaver and Haskell 1967).

Seeds (cheatgrass, wheatgrass, and pinyon) are the main food items, but the bulbs of some plants are also eaten. Insects, particularly grasshoppers, are taken whenever available. In arid regions, these birds are limited to areas of open water.

Major reclamation efforts should be directed toward providing expanses of rocky slopes with sagebrush, grass, and other shrubby cover. This can be incorporated into a high-wall reclamation program. Open water must be provided, although the distribution is uncertain. Because they are wide-ranging birds, one source of water per one or two square miles appears adequate (Christensen 1954).

Mourning Doves. Mourning doves are ubiquitous throughout the semi-open areas of the West. They occur in habitats as different as desert shrublands, mountain meadows. and marshes. They will nest in trees and on the ground when cover abounds. Brushy edges, clumps of conifers, and shrubs all provide roosting and nesting cover. Their primary food is seeds, particularly of grasses, grains, forbs, and "weeds" (USDE FWS/OBS 1978).

Its wide-ranging behavior and broad habitat tolerances make this species relatively easy to accommodate in a reclamation plan. As long as a wide variety of seed-producing grasses and forbs and adequate nesting cover are provided, this species should readily repopulate reclaimed areas. Leaving strips of unharvested grain along the edges of untilled wild areas such as ridges, swales, and drainages will also benefit doves. Since doves do not scratch for food, feeding grounds should be free of heavy, grassy ground cover. Doves do require water at least twice a day. Open water is usable if the banks are not too steep and are free of thick vegetation.

Ring-Necked Pheasant. The ring-necked pheasant adapts well to cultivated agricultural areas throughout the West. Reclamation plans directed at providing agricultural crop lands can be beneficial for pheasants if some grain strips or patches are left unharvested and if nesting cover is provided in the form of dense-growing legumes, grasses, and forbs. Patches of food are better than long, narrow strips. Patches need not be bigger than an acre. Several small patches are better than one large patch. All food patches should be near escape cover consisting of woody brush species or clumps of conifers.

Plants which provide food for pheasants include all of the agricultural grains as well as alfalfa, sweetclover, ragweed, Russian thistle, dandelion, and sunflower (Martin et al. 1951). Most of these species provide excellent nesting cover if left in dense patches (USDI FWS/OBS 1978). Riparian and marshy areas provide excellent cover if adequate dry ground exists for nesting and if nearby food plants are plentiful.

Winter cover is often the most critical element restricting pheasant populations. They cannot exist where snow accumulations bury food and cover. Brushy windbreaks in themselves will not be adequate if they drift over with snow. Of more value are large patches of tall wild and/or cultivated crops which remain snow-free and available throughout the year. Although long, narrow, brushy fencerows can provide nesting cover, they also concentrate predators and increase the possibility of having a high proportion of nests destroyed. Again patches of habitat will produce more broods than will an equal amount of habitat existing as long, narrow strips. For additional guidelines see the agricultural-wildlife habitat section in this chapter.

Raptors

Birds of prey represent a unique challenge to the resource manager. As a group, raptors are conspicuous and well-recognized by the public. Historically, they have been persecuted for alleged depredations, and recently they have become victims of pesticides and other toxic substances. Their position near the top of the ecological pyramid makes them vulnerable to pertubations experienced by species lower in the food chain. And the specialized ecological requirement of many raptors leaves them susceptible to even minor habitat alterations.

Raptors have recently become the symbol of ecological well-being of our environment (Olendroff et al. 1980). As a result, many of the birds of prey have gained significant political importance, perhaps even exceeding their ecological importance.

As a result of the changes in public awareness, all raptors are now protected by State or Federal laws. In 1972, all hawks, eagles, falcons, and owls were placed under Federal protection when Congress passed an amendment to the Migratory Bird Treaty Act. And the Endangered Species Act of 1973 firmly commits us to protecting all species, not only those which face the immediate threat of extinction. In recent years, most States have also enacted laws which specifically protect all hawks, falcons, eagles, and owls. Consequently, before any mining permit is granted, the pre-mining survey and the reclamation plan have to account for all raptors which occur on and near the site, whether as nesting, migratory, or wintering populations. And because of the Federal and State laws, permits may be required from both levels of government before any work, including population surveys, can be conducted. Officials of both the State resource management agencies and the U.S. Fish and Wildlife Service should be contacted before any field work begins.

As with some of the other species discussed in this report, there is no clear public consensus as to what the goals of the raptor management program should be. Some people would like the number of raptors maximized regardless of the means. Others feel the wilderness value of raptors will be lost if they are present only because of artificial nesting structures or "domestication" programs (Snyder and Snyder 1975). The question of philosophical goals exceeds the scope of this paper. As managers charged with overseeing energy development and impact mitigation, our primary goal is to restore the biotic resources at least to the level before disturbance and, whenever possible, to the historic carrying capacity. To achieve these goals, we must first determine the pre-disturbance raptor population.

The best currently available survey techniques are described in the following publication:

Call, M.W. (1978). Nesting Habitats and Surveying Techniques for Common Western Raptors. USDI/BLM Tech. Note 316. 115p.

Most State wildlife departments have their own censusing techniques and procedures. Although they may differ very little from the techniques presented in the above publication, it is recommended that all survey work be coordinated with local wildlife managers to insure compatible data for accurate comparisons.

The raptor survey should first determine which species are present, and during which season. For example, American rough-legged hawks and bald eagles may occur only during the winter months, while golden eagles and great-horned owls may be year-round residents. The survey should also determine densities, distribution, and habitat affinities for all of the species. Habitat utilization can be anticipated from published literature and the survey should function in part as "ground truthing" anticipated affinities.

Determining habitat utilization or how individual birds use any given area can be a time-consuming task, but one which will yield information of extreme importance. For example, the pre-mining survey may identify two active golden eagle nests along the periphery of the proposed mine. By determining just the nest locations, it may appear that mine development will jeopardize both nests and that this can only be avoided with costly mine plan alterations and/or nest relocations. (Current laws state that no mining can occur within a one-quarter mile radius of an active golden eagle nest.) When individual eagles are observed and their daily habitat use patterns become known, it may be that the nests are not in the center of their respective home ranges, but instead near their edges. Consequently, although one nest is within several hundred meters of the proposed mine, very little if any of the habitat used by these birds will be disturbed. Conversely, the territory belonging to the second nesting pair could encompass the entire mine site and thus be subjected to almost complete annihilation, even though the nest may be beyond the one-quarter mile range prescribed by law. Obviously, the mining activity will severely impact one pair of eagles and not the other, although both are about equal distance from the site.

The previous scenario involves the actual elimination of habitat. This may include destruction of nest sites, hunting range, or critical roosting areas. (The latter may be of primary concern to wintering raptor species.) But disturbance may take on another form; habitat can remain untouched but be rendered useless because of the activities associated with mining. For example, roads may pass so close to nests, hunting habitat, or roosting cover that the raptors will not use the sites. Or, transmission lines may prove fatal to raptors because of poor placement or construction electrocutions or collisions.

The following is a list of raptor survey considerations:

> The location of raptor nest and roosting areas should not be divulged to anyone but the appropriate authorities.
>
> Unless survey objectives demand knowledge of clutch size, raptor nests should not be approached until the young are hatched.

> Every nest visit should be carried out with the fewest people and for the shortest period (preferably less than 5 minutes) possible, and should occur as infrequently as possible (never twice in one day).
>
> Nest visits should not occur during inclement weather.
>
> Observations should be made from a distance great enough that adults are not forced to leave the nest. This distance will vary with species and location.
>
> Nest visits should not occur during the last week that the fledglings are in the nest. Disturbance at this time could force the young to leave their nests before they are capable of flying and landing safely.
>
> Mining officials should be encouraged to inform their personnel of the legal protection granted all raptors and of the consequences of disturbing raptors or their nests.

A raptor management plan must consider several points: First, because of their position at the top of the food chain, raptors are dependent upon other animals for food. Therefore, the first step in a raptor management plan must be the establishment of a stable and diverse habitat, one which supports an abundant and diversified prey population (Olendorff R. et al. 1978).

Second, most raptors have specific nesting requirements which, if not provided for, will result in the birds not using the area even though all other requirements are met.

Third, many species do not reside in one area all year, and when individuals are present, their response to disturbance varies with their own activity patterns. Constant or severe disturbance at or near a nest site during the initial phases of nest establishment and on through egg laying and incubation will cause most species to abandon the site. In contrast, few species will abandon a nest once the young have hatched. Similarly, disturbance on or near seasonal roosting and feeding sites may render these areas useless to raptors and force them to leave the area entirely or to utilize less favorable habitat. Simply changing the timing of short-term disturbances may be all that is required to insure successful raptor reproduction. Therefore, a successful management plan must take into account more than just species presence. It must also provide all the seasonal habitat requirements for each species and insure that these habitat features are available when needed.

To meet this challenge, the resource manager must have a knowledge of basic raptor biology. The following publications provide specific ecological information and management recommendations for a number of species significant in this region:

Habitat Managmenet Series for Unique and Endangered species. USDI-BLM Tech. Notes.

Additional information about raptor management and biology can be found in the following publications:

Olendorff, R., R. Motroni and M. Call. 1980. Raptor Management: The State of the Art in 1980. USDI-BLM Tech. Report No. T/N 345. 70p.

Call, M. 1979b. Habitat Management Guides for Birds of Prey. USDI-BLM Tech. Rept. No. T/N 338. 70p.

Murphy, J. 1978. Management Considerations for Some Western Hawks. Trans. Forty-Third N. American Wildl. Conf. p. 241-251.

Brown, L. 1976. Birds of Prey. New York, A. and W. Publ., Inc.

Brown, L. 1976. Eagles of the World. New York. Universe Bks.

Craighead, J. and F. Craighead Jr. 1969. Hawks, Owls and Wildlife. New York. Dover Publ., Inc.

Brown, L. and D. Amadon. 1968. Eagles, Hawks and Falcons of the World. 2 vols. New York. McGraw-Hill Book Co.

Bent, A. 1937 and 1938. Life Histories of North American Birds of Prey. 2 vols. U.S. Nat. Mus. Bull., No. 169 and 170.

Benson, P. 1982. Prevention of Golden Eagle Electrocution. Electric Power Research Inst. Research Proj. 1002. EA-2680. Palo Alto, Ca., 52p.

Howard, R. and J. Gore, (eds.). 1980. Workshop on Raptors and Energy Developments. Proc. of Workshop. Bonneville Power Admin., Boise, Id. 125p.

Bald Eagle. The bald eagle is protected by the Bald Eagle Protection Act and the Endangered Species Act. Bald eagles will be encountered primarily as winter visitors and only rarely as nesting pairs. Wintering individuals occur in this region from early to mid-November through mid-March. They usually occur in areas with either large bodies of open water or valleys with roosting cliffs or large trees (Platt 1976; Edwards 1969; Swisher 1964). Winter food consists of domestic and wild carrion or fish. Besides a food source, wintering bald eagles require night-time roosting sites which can be either large cottonwood or willow trees or thick stands of conifers in mountain canyons. Sometimes feeding areas may be separated from roosting sites by as much as 16 to 24 km (10 to 15 mi) (Swisher 1964).

Bald eagles nest on cliff faces and in large trees along lakes and rivers. Most tree nests are from 15 to 27 m (50 to 90 ft) above ground and usually in the largest tree in the area (Call 1978). They have been known to nest on artificial nest structures but not with great regularity or success (Olendorff et al. 1980). Under no circumstances should an active or recently active bald eagle nest be disturbed.

Buffer zones should be established around active nests, alternate nest sites, favored roost trees, and winter roosting areas. The primary zone should be no smaller than 20 acres and should remain unaltered. The primary zone surrounding the nest should be posted against all unauthorized human entry from mid-February to early July. The primary zone around winter roosting areas should be posted against all unauthorized visitation from mid-November to mid-March.

The size of the secondary zone may vary according to topography, but may extend as much as 400 m (one-quarter mi) around the site.

The primary and secondary zones surrounding nest sites, the winter roosting areas, and the critical feeding areas should all remain free of a permanent occupancy (mines, processing plants, loading facilities, and administrative facilities). The construction of non-occupancy structures such as conveyor belts, pipelines, and transmission lines can occur during the months when eagles are not present, provided such structures do not severely alter the habitat features of the site. If construction is planned near winter roosting areas, it should preferably occur when wintering birds are not yet in the area; if it must occur when birds are present, daily human activity should not begin until 1 hour after sunrise and it should cease 1.5 hours before sunset. This will provide the roosting birds ample time to enter and exit the roosting area with no interference from construction activity.

Nesting season begins with site selection in February or March, depending on latitude and altitude. The young have usually left the nest by early July. Bald eagle nest sites should not be visited except by an authority on the species and then only for specific research purposes and with proper authorization.

Golden Eagles. Golden eagles are protected by the Migratory Bird Treaty Act, the Bald Eagle Protection Act, and by State laws. In most locations, golden eagles are present year-round, although it is not certain if the birds seen during the winter are also the nesting individuals or if the species undergoes a "leap-frog" phenomenon whereby northern birds move south to winter in regions vacated by nesting birds.

Golden eagle nests are generally located on cliffs and occasionally in large trees where cliffs are lacking. In areas where trees are lacking and cliffs are localized, close nesting of several pairs (2 or 3 pairs within 1 or 2 square miles) may occur (Camenzind 1970). In these cases, a knowledge of how the habitat is partitioned between the pairs and the spatial relationship of the nest to the territory can play a key role in conducting mining activities.

Eggs are laid from late February to the end of March, depending on latitude and altitude. Incubation lasts approximately 42 days and the young remain in the nest for 9 to 10 weeks. Nests will be abandoned if the birds are severely disturbed during incubation. Nests are rarely abandoned once the young have hatched, although sporadic disturbance may result in missed feedings which can lead to weakened young or possible starvation.

Mining operations can either destroy nesting and/or feeding areas or disturb these areas rendering them useless. Feeding areas can be replaced during reclamation if the prey base is reestablished. Potential prey items include almost any of the diurnal mammals ranging in size from ground squirrels to marmots. Young of even larger mammals (antelope and deer fawns) are on occasion taken by golden eagles, as are upland game birds. An adequate prey base should include a diversity of species to insure a year-round food supply.

Golden eagles have been known to nest on man-made structures (Camenzind 1970), although constructing platforms specifically for golden eagles has met with only limited success (Olendorff et al. 1980; Call 1979b). The preferred method of providing nesting sites is to utilize the mine-end high walls, particularly when it is composed of solid material such as rock or clays. Until the laws restricting mine-end high walls are modified, this may not be a viable part of the reclamation plan.

Nesting platforms should be at least 5 to 8 m (15 to 25 ft) off the ground and provide some wind and sun protection for the nest itself. Platforms should be at least 120 cm (4 ft) square. A solid wood platform will be satisfactory but one made of welded wire (5 by 10 cm) will allow for better attachment of nesting material, will drain rapidly, and will generally out-last a wood platform. Fifteen to 30 cm (6 to 12 in) of nest material can be placed on the platform to simulate a nest and help to attract eagles.

Little has been mentioned in the literature about constructing a nesting complex. This should consist of two to three nest platforms within several hundred linear meters, with each oriented (toward the sun and prevailing winds) slightly differently from southeast to southwest. This will provide the nesting pair with options in site selection as well as a roosting site for the adults while away from the nest.

If a high wall can be incorporated into the reclamation plan, then the nest should be at least 8 to 10 m (25 to 30 ft) from the bottom or about two-thirds to three-quarters of the way up the cliff face. Ledges can be left in place and should measure at least 3 m (6 ft) long and 1.2 m (4 ft) deep. Overhangs should be left in place (at least 1.5 to 2 m above the ledge) to provide weather and sun protection. The nest ledge should face southeast, south, or southwest. More than one nest ledge should exist in a nesting complex, and these should all offer slightly different features, including aspect and size. Whenever possible, some nest material should be placed on the ledge to encourage use.

Nest sites should be hidden from traffic areas or activity centers. Care should be taken not to locate a nesting complex too near (less than 0.5 to 0.75 km) existing or proposed upland game bird leks or nesting and wintering areas. Nests and roosting structures too close to these sites can result in increased predator losses.

Two possibilities exist for golden eagle habitat restoration: First, the reclaimed site can be incorporated into the territory of an existing territory; second, if the site is sufficiently large and contains all the necessary elements, new birds can be encouraged to use the area. The latter would involve the establishment of a nesting and roosting complex as previously described.

Several years may be required before new birds will occupy the site, consequently the success of the effort may not be determined in one season. The manager is obligated to provide all the components of eagle habitat; some elements, such as nesting and perching sites, should be put in place as soon as the land surface contouring is completed, but it may require several years for prey species to achieve densities capable of supporting eagles.

Biologists in Wyoming have had success in moving occupied golden eagle nests away from mining activities (Stelter 1981). They have constructed nesting platform complexes with nests 100 to 200 m from the occupied nest and in the direction of the intended move and within sight of the occupied nest. The eaglets were then moved to the new nest and, within hours, the adults found them and continued their parenting routine. After several days, the young were again moved to another nest site. This procedure was repeated until the eaglets were out of the path of the intended mining activity. At this time all but the last nest site were removed. Four such movements were accomplished in 1981. Movements of this sort should occur only when the young are between 2 and 6 weeks of age and only during warm, dry weather.

If nest movement is planned, it should be closely coordinated with experts from State and/or Federal agencies who are experienced with raptor management. Nests should always be moved within the same territory and not out of the territory. Such moves could jeopardize the success of both adults and young. To insure the integrity of the move, adjacent nests and territory boundaries must be located.

Osprey. Osprey, or fish hawks, are always associated with open water and will be found in this region only as nesting or migrating individuals. Few, if any, winter in this region. Their nesting habitat requirements are similar to those of the bald eagle, although the osprey can be associated with much smaller bodies of water.

Osprey prefer to nest on the tops of dead snags or on the tops of trees with dead tops. They will utilize man-made nesting platforms in suitable locations around lakes and reservoirs, and along clear, flowing streams. If osprey are already nesting in the vicinity and if large bodies of clear, open water are to be a part of the reclamation plan, the inclusion of nesting platforms and an excellent fish population may attract osprey to the site.

A nesting complex should include two or three potential nest sites and a similar number of perch sites. The complex should provide good security and visibility for the birds. The nest platforms should be 10 to 30 m (30 to 100 ft) above ground. Rock pinnacles jutting out of the mine-end high wall may also provide nesting sites for osprey. Osprey appear to have no requirements for sun and wind protection.

Protecting nest sites and feeding areas from human disturbance can be accomplished with the use of buffer zones. Richardson (1980) outlines a buffer zone system whereby the primary zone extends 200 m from the nest and the secondary zone extends from 200 to 400 m from the nest. Human entry into the primary zone should be prohibited between early May and mid-July. Entry into the secondary zone between these dates should occur only where topography and/or vegetation provide a visual screen between the nest and humans.

Major human developments, such as mines and buildings, should not occur at any time in the primary or secondary zone. Non-occupancy structures or facilities such as roadways, pipelines, and conveyor belts should not occur in the primary or secondary zones from early May to mid-July.

Buteos. Buteos are the broad-winged, soaring hawks such as the red-tailed hawk, ferruginous hawk, Swainson's hawk and American rough-legged hawk. All but the last one are common nesting species in the NRMGPR which migrate out for the winter months. The American rough-legged hawk nests in the northern tundra and winters in this region. Because of their relative abundance, all of these species readily reoccupy a site when habitat requirements are met.

The red-tailed hawk is the most common of the buteos. Depending on latitude and altitude, they return to their nesting areas in late March and early April. Red-tailed hawks nest on a wide variety of sites, usually 5 to 10 m (15 to 32 ft) above the ground. They are as likely to nest high on sheer cliffs or relatively accessible "walk in" ledges as they are to nest in trees. They will, on occasion, nest on man-made structures such as power poles or nesting platforms placed for golden eagle. As with the golden eagle, red-tailed hawks appear to require some shelter from the sun and wind at the nest.

Red-tailed hawks are quite tolerant of human activity, although they will abandon eggs if unduly disturbed during incubation.

The reclamation plan should emphasize establishment of a diverse prey base made up of small mammals, including mice, chipmunks, ground squirrels, and cottontail rabbits as well as small birds and reptiles. Nest sites can be created on mine-end high walls and with artificial nest platforms. Nesting complexes should include at least two potential sites as well as two or three nearby perching sites. These should all be provided with some sun and wind shelter but should still allow for good visibility of the surroudings.

Trees should be planted where site conditions are favorable for their growth and survival. These will eventually provide the best nesting and roosting sites.

The ferruginous hawk species is associated more with grassland and sagebrush areas than any of the other buteos. Ferruginous hawks commonly nest on rocky pinnacles, low ridges, and cut-banks extending from 1 to 5 m (3 to 16 ft) in height. They will also nest on tall sage and low juniper trees. They have the widest latitude in nest sites of any of the buteos (Weston 1970).

Nests are usually made of branches up to 5 cm (2 in.) in diameter. These can be of almost any species present but are most commonly sagebrush. The nests are lined with the inner bark of sage and juniper. Often the bowl of the nest will include foreign items such as lengths of rope, dry cow dung, and trash paper. Ferruginous hawk nests are almost always completely exposed to the wind and sun.

Ferruginous hawks are very intolerant of disturbance during incubation, which begins in early May and continues for about 35 days. However, this species will readily nest on man-made structures such as cairns and nesting platforms (Call 1979b).

The success of platforms can be greatly increased if they include nest materials such as sagebrush and short, broken deciduous branches. These may have to be wired onto the platform to keep the wind from blowing them away. Smaller sticks and grass can be woven into the matrix. The platforms should be from 2 to 3 m (6 to 8 ft) above ground and at least 0.5 km from roads to prevent disturbance from humans.

Before nesting will occur on a reclaimed site, a suitable prey base must exist. This ideally consists of jackrabbits, cottontail rabbits, prairie dogs, and ground squirrels (Howard and Wolfe 1976). The absence of prey items should not preclude the construction of nest sites, because with adequate habitat diversity, the prey species will eventually return.

Swainson's hawks are the smallest and most docile of the buteos and are closely associated with open grass and sagelands. They nest almost exclusively in trees and tall bushes along streams and at the edge of forest lands. They often nest in trees planted as windbreaks around ranch buildings. Their nests are flimsy compared with those of the other buteos and consist of small branches, weeds, and leaves. Nesting begins in May, usually 2 to 3 weeks after the red-tailed hawks. They are the least susceptible to disturbance during incubation of any of the buteos. Their food preferences tend toward species smaller than cottontail rabbits, including items as small as grasshoppers.

Because of their habit of nesting in trees, reclamation efforts for Swainson's hawks should include the planting of cottonwoods and other fast-growing deciduous trees. It may require many years for nesting sites to be available for these hawks, but such long-range planning must be a part of the reclamation effort.

The American rough-legged hawk species nests in northern Canada and Alaska and migrates to the NRMGPR to winter. While wintering in this region, their diet includes cottontail rabbits and jackrabbits. They will frequently eat domestic carrion and road-killed rabbits and hares. Because of this habit, rough-legged hawks are often observed on power poles and trees along roadways where they are subjected to illegal shooting by ignorant people.

The essential ingredient of rough-legged hawk winter habitat includes an abundant prey base, perch sites, and freedom from illegal shooting.

Accipiters. The accipiters are fast-flying birds of prey specializing in capturing small prey such as birds and small mammals. Four species can be expected in this region: the northern harrier (marsh hawk), Cooper's hawk, sharp-shinned hawk, and goshawk. All but the northern harrier are associated with timbered areas and consequently will not be discussed in great detail.

The northern harrier or marsh hawk prefers to nest in the vicinity of ponds, rivers, marshes, grassy ravines, and thick grass/sagebrush areas. The nests are located on the ground and are well concealed with vegetation. The adults are often observed flying low over meadows or agricultural fields hunting for small birds and mammals as well as grasshoppers and small reptiles.

Harriers should be encouraged because they can play a beneficial role in helping to control mice and grasshoppers, which can become a problem during the revegetation program. Because of their habit of nesting on the ground, harriers may be one of the first raptors to reoccupy a reclaimed site. Because harriers prefer to nest in riparian habitat, establishment and maintenance of this habitat type is the single most beneficial reclamation procedure for them.

Cooper's hawks, sharp-shinned hawks and goshawks are all species which nest and hunt in and along the edges of forest habitat. Until this habitat type is reestablished, these species will not occur. When reforestation is part of the reclamation plan, the most beneficial habitat for these birds would include mixed native conifers and deciduous stands with scattered, brushy openings.

Falcons. As a group, falcons represent an interesting management problem. The peregrine falcon is listed as endangered, and the prairie falcon is relatively common in some areas but considered sensitive by most managment agencies. The kestrel or sparrow hawk is one of the most common and widespread raptors in North America. The merlin is listed as uncommon in this region. Of the four, only the prairie falcon may be seen in this region year-round. It has not been determined if the birds wintering in the NRMGPR are local residents or individuals nesting in other regions and migrating here for the winter.

The peregrine falcon is almost always found nesting within 1.5 to 3 km (1 to 2 mi) of open water and extensive riparian and shoreline habitat. This habitat usually supports an abundant and diverse bird population, the primary food source for this species.

Peregrines nest exclusively on cliffs which typically exceed 30 m (100 ft) and, in the NRMGPR, almost always at sites with southern exposures.

Because of their endangered status, mining activity proposed near active peregrine eyries will have to be severely modified if in fact a permit is issued. If this species is suspected of occurring in the area, State and Federal officials must be contacted to expedite further planning.

Because peregrine falcons require a unique combination of communities rich in bird life (aquatic and riparian) and high cliffs, it is difficult to actually "create" habitat for this species. The inclusion of riparian habitat, when appropriate, is perhaps the single most important habitat element which can be at least partially provided in the reclamation plan.

Prairie falcons are relatively uncommon over most of the grass and sagebrush lands of this region (Snow 1974). They require large rock outcrops and cliff faces (5 to 15 meters high) for nesting sites. They commonly nest on sheltered ledges and in natural caves. An active eyrie will usually contain two or more alternate nest sites within 50 m or less. Different sites may be used in different years.

Occasionally, prairie falcons will nest in abandoned golden eagle or red-tailed hawk nests if these have overhead ledges. Prairie falcons do not build stick nests, they simply lay their eggs in a "scrapped" out bowl on the ledge. Nest sites usually overlook large expanses of open, treeless, hunting range. Their favorite foods include small birds, mammals (ground squirrels and mice), and occasionally small reptiles.

Prairie falcons are intolerant of human disturbance, particularly while incubating. Once the young have hatched, the adults become tenacious defenders of their eyrie. Prairie falcons will often return to a nest that they abandoned the year before. Little can be done to protect a nesting site if mining activity is scheduled to occur on the site. However, curtailing or limiting activity near an active eyrie during the early-May to mid-June incubation period will help insure nesting success for that season.

Because of the special nesting requirements of the prairie falcon, only large rock outcroppings and mine-end high walls can provide potential nesting sites. Several protected ledges and/or caves must be provided for each eyrie. Ledges or caves can be blasted into the side of such cliffs. Sites facing southeast, southwest, and west will have the greatest chance of being utilized by prairie falcons. Other than the nest site, the most important reclamation effort centers on providing an abundant and diversified prey population.

The kestrel or sparrow hawk is one of the most common and widespread raptors of this region. It is the smallest of our falcons and feeds on mice, small birds, and insects, particularly grasshoppers. It resides here only during the summer months, appearing in early April and leaving in October.

Kestrels nest in a variety of natural features, including small caves, crevices, and protected ledges on rocky outcroppings and cliff faces. They also nest in old woodpecker holes and hollow trees as well as in abandoned buildings and nest boxes. Its abundance, mobility, and tolerance of human activity make the kestrel one of the first raptors to utilize reclaimed habitat.

Numerous individuals have had success in attracting kestrels to artificial nest boxes (Hamerstrom et al. 1973, Byers 1980). These can be used in place of natural nest sites, but the long-range goal of the resource manager should be one of providing natural nesting sites.

Nest boxes should be 20 to 25 cm square (8 to 10 in) and 50 to 60 cm high (20 to 24 in). The entrance hole should be 7.5 to 10 cm in diameter (3 to 4 in) and about three-quarters of the way up the side of the box.

The boxes should be placed 3 to 4 m (12 to 16 ft) above ground on poles or in trees if available. The openings should face south or southwast. Nest sites need be no closer than 1 per 10 acres, although each site should contain one or two alternate nests. Sites should be located near trees, fences, or communication lines, to provide necesary roosting sites for the birds. Nest boxes should be checked at least once early in the nesting season to remove undesirable species such as starlings which may also use the boxes.

As with all raptors, the most important element in the life cycle of the kestrel is the need for an abundant and stable prey population. For kestrels, this means mice, small birds, and insects, organisms which are often in abundance on reclaimed sites.

Merlins, or pigeon hawks, are uncommon nesting falcons in this region. They nest primarily along prairie openings and river bottoms. Almost all nesting occurs in unused magpie and crow nests. They are known to nest only rarely in tree cavities or on the ground. They feed on small birds, insects, and occasionally on small mammals.

Since merlins are very dependent upon old magpie and crow nests for their own nesting success, it is unlikely that they will appear at a reclamation site except as migrants. Providing riparian habitat with an abundance of trees and adjacent native prairie species will be the single most important action the manager can take to benefit merlins.

Owls. As many as 11 species of owls occur in portions of the NRMGPR. Of these, six are uncommon in this region and are associated with coniferous forests (saw-whet, boreal, screech, pigmy, flammulated, and great gray). The great gray is probably restricted to the mountainous coniferous forests of the Yellowstone portion of this region. It nests in inactive raven or goshawk nests and on the broken ends of tall snags measuring at least 0.5 m (20 in.) in diameter. The other five species of forest owls nest in abandoned woodpecker holes or in natural cavities in large trees. The flammulated, screech and saw-whet owls will use nest boxes similar in size and shape to those described for the kestrel.

The mitigation measure which will benefit these species most involves minimizing disturbance to existing habitat. The primary reclamation effort for these species consists of replacing any coniferous forest lost in the mining operation.

The long-eared owl is also closely associated with coniferous forests but is somewhat more common than the six species previously mentioned. This owl also nests on unoccupied stick nests built by other species. Any reclamation effort intended to help this species will first have to establish a forest environment with its associated prey species and nesting habitat. The long-eared owl accepts artificial nest structures, but these must be placed in mature forests.

The barn owl is relatively tolerant of human presence and occurs in a variety of habitats, including riparian zones and forest edges. The barn owl is on the periphery of its range throughout most of the NRMGPR. It nests in natural tree cavities, abandoned buildings, holes in cut banks, and in man-made nest boxes. If this species is known to occur in an area proposed for mining, measures can be taken to increase nesting sites. These include digging holes into clay and rock banks and constructing nest boxes. Bank holes should be at least 2 m (6 ft) above the base of the bank and should be approximately 20 to 30 cm (7 to 12 in.) in diameter and extend at least 2 m into the bank.

Nest boxes should be at least 35 to 40 cm (14 to 18 in) square, 60 cm (24 in) high, and have an entrance at least 20 to 30 cm (7 to 12 in.) in diameter. Boxes are best placed in trees along forest edges or in riparian areas.

The great-horned owl is the most widely distributed and certainly the most common owl in North America. It is a year-round resident of this region and has a high tolerance of humans. It will nest in abandoned hawk nests in trees, on cliffs, in tree cavities, and on broken snags. Ecologically, it is the nocturnal counterpart of the red-tailed hawk; the management recommendations suitable for the red-tailed hawk are applicable for the great-horned owl. They do not however, build their own nests, and if nesting platforms are to be put out for this species, they should include a stick nest.

The short-eared owl is the nocturnal counterpart of the marsh hawk or northern harrier. They usually nest on the ground in riparian areas or moist meadows with a dense and/or grassy cover. Because the nesting requirements include relatively fast-growing riparian grasses and woody species, the short-eared owl may be one of the first owls to nest in the reclaimed site once habitat conditions are met. Mitigation measures described for the northern harrier and for riparian habitat will best suit the short-eared owl.

The burrowing owl is the most specialized of all the owl species. In 1973, the U.S. Department of the Interior listed the burrowing owl as a "status- undetermined" species. As recently as 1966 it was listed as "rare" throughout most of its range.

In this region, the burrowing owl nests underground in abandoned prairie dog, rabbit, or badger burrows. The decline in burrowing owl numbers is directly related to the destruction of prairie dog towns. If any mining activity is proposed in an active prairie dog town, a thorough survey should be made in June and early July to determine whether or not burrowing owls are present.

They are readily visible, particularly in the mornings and late afternoons when they can be seen standing on prairie dog mounds, fenceposts, or other slightly raised objects. Nest burrows are conspicuous during these months because the entrance will be littered with insect and small mammal remains. Favored perching mounds will also be "white-washed" with excrement.

Burrowing owls have been known to nest in man-made nest boxes buried underground (Call 1979, Landry 1977). The top of the nest box should be between 20 and 50 cm (8 to 20 in) underground and 30 to 40 cm (13 to 18 in) across. The tunnel leading to the nest chamber should be from 2 to 3 m long with one right-angle turn near the nest box. The right angle turn should be several cm lower than the nest box itself and have numerous holes drilled through the bottom to permit water to drain from the tunnel and not run into the nest box.

Because burrowing owls will often nest in close proximity to one another, nest boxes can be placed as close as 100 meters. Several low (less than 1 m above surrounding features) mounds or posts placed in the proximity of nest boxes will provide the owls with perching and hunting sites. Besides the availability of nesting burrows, burrowing owl habitat consists of open lands, short vegetation, and a prey base consisting of insects and small mammals.

Nesting sites should be established only in areas adjacent to large expanses of existing burrowing owl habitat and preferably in proximity to known nesting populations. Although well intended, the establishment of isolated burrowing owl habitat may be fruitless if existing populations and/or nearby habitat is not in place.

Mammals

The discussion of mammals will be divided into three sections: small mammals, including opossums, shrews, bats, pikas, rabbits, hares, and rodents; carnivorous mammals (weasels, bears, dogs, and cats); and the artiodactyles, or those species commonly referred to as big game, such as deer, antelope, elk, moose, and bighorn sheep.

Small Mamals

In the past, small mammals received little attention in reclamation efforts. This is due to the low economic importance placed on this group and because most of these species will repopulate an area once suitable habitat exists. As a result, there is little information available describing management techniques beneficial to these species. From a manager's standpoint, a knowledge of basic habitat requirements and life cycles will be enough to direct the reclamation effort to a conclusion beneficial to small mammals.

The following publications provide basic natural history information for these and all other North American mammals:

Cahalane, V. 1961. Mammals of North America. Macmillian Co. New York. 682p.

Allen, T. (ed.). 1979. Wild Animals of North America. Nat. Geo. Soc., Wash. D.C. 406p.

The following publication, although not dealing exclusively with mammals, provides an excellent background on the concept of mitigation in general and as it pertains to specific animal groups and habitats. All resource managers should have it available.

USDA Forest Service. 1979. The Mitigation Symposium. USDA For. Ser. Gen. Tech. Rept. RM-65. 684p.

Opossums. Opossums occur only in the eastern reaches of the NRMGPR and are limited to wooded habitats usually following watercourses. Their omnivorous feeding habits and tolerance of man make them a highly adaptable species. Current range restrictions are probable determined by winter cold, snow depth, and lack of forest cover.

Shrews. Shrews are the smallest mammals in North America and are primarily carnivorous, eating insects and other animal matter. Most shrews are restricted to moist habitats, although some occur in the sagebrush/grassland communities of the West. Their extremely high metabolic rate requires that they consume large quantities of food daily, sometimes more than their own weight.

General habitat requirements for shrews include riparian vegetation and diverse plant communities. The ground surface should provide a variety of micro-habitats such as rock piles and layers of organic litter. These features are characteristic of mature plant communities but can be encouraged and duplicated in part with the addition of rock piles and the planting of diverse grass, forb, and woody species in moist and sheltered areas.

Bats. Bats have specific roosting and feeding habitat requirements. Roosting areas consist of large, hollow trees, buildings with cracks and openings leading into sheltered and darkened walls and roofs, and rock cliff faces with deep and sheltered fractures.

Feeding habitat consists of moist areas with abundant insect populations and is best provided by riparian habitat and areas of standing shallow water.

Pikas, Rabbits and Hares. This is the only group of small mammals with a conspicuous, positive economic impact in this region. Small game hunting licenses are sold for cottontail seasons, and jackrabbits provide targets for sport shooters.

Pikas are the most habitat-specific species in this group. They require stable rock-talus slides usually above 2,100 m (7,000 ft) in subalpine and alpine communities. There must be areas of diverse grass, forb, and woody shrub habitat immediately adjacent to and scattered within the rock slides to provide feeding habitat for pikas. The rock slides must provide micro-habitat features at ground level consisting of numerous tunnels and rocky overhangs. This can best be provided if the rocks are at least 25 cm (10 in.) in diameter and irregular in shape as opposed to flat.

The desert cottontail rabbit occurs throughout the region in shortgrass, mixed sagebrush-grasslands, pinyon-juniper, and creosote brush-desert habitats. Additional cover requirements include brush and rock piles as well as abandoned marmot, badger, and prairie dog burrows. Food preferences are about equally divided between a variety of grasses and forbs. Cottontail rabbits will repopulate a reclaimed site once the habitat requirements are met.

Three species of hares occur in this region: the snowshoe hare, and the white-tailed and black-tailed jackrabbits. Hares do not utilize burrows for cover, although they do use depressions (burrow entrances) and shrubby sheltered areas for protection from wind and weather.

Snowshoe hare preferred habitats are the Engelmann, spruce-alpine fir forest and willow thickets along streams. Without this habitat type, snowshoe hares will not occur. If these habitat criteria can be met in a reclamation plan and if snowshoe hares exist in nearby, adjacent habitat, they will repopulate the site naturally.

White-tailed jackrabbits occur in the northern portion of this region while black-tailed jackrabbits occur in the south. Both require a mixture of grasslands and shrubby cover, usually sagebrush, rabbit brush, or salt bush. Summer foods consist of grass and forbs while the winter diet shifts more to the shrubby species.

Jackrabbits are highly mobile and will repopulate an area when habitat becomes available. They can become a problem during the early stages of revegetation because of their preference for succulent young grasses and forbs. To protect these areas, buffer strips cleared of all shrubby cover can be created around the revegetated areas. These zones should be at least 300 m (nearly 1,000 ft) wide, since jackrabbits will seldom venture more than this distance from escape cover. The addition of wooden perching poles will attract raptors to the area. These species will help keep jackrabbit populations at low levels and away from revegetated sites.

Rodents. Taxonomically, the rodents include all the mice, flying, tree and ground squirrels, gophers, prairie dogs, marmots, beaver, muskrats, and porcupines. All of the species of mice inhabiting this region have specific habitat requirements. The simplest way to insure diverse rodent populations is to establish diverse habitats. This should include a variety of grass, forb, and woody species in mixtures and in blocks correlated to appropriate sites based upon soils, drainage, aspect, and exposure.

Most species of rodents will invade an area as soon as their habitat requirements are met. In fact, like jackrabbits, rodents may become a problem at revegetated sites by "over grazing" the new growth before it can establish itself. In such situations, attracting predators, especially raptors (with perching and nesting sites), to the area should be the first method used to control rodents.

Flying and tree squirrel habitat can be provided only with extensive stands of mixed, mature conifer and hardwood forests. Unless this habitat is adjacent to the mine site or is the goal of the reclamation effort, these species will not enter into the reclamation plan.

Chipmunks have habitat requirements similar to those of the tree squirrels; however, they depend more heavily upon the condition of the understory than do the tree squirrels. Chipmunks require a mixed forb and grass understory with abundant escape cover in the form of rocks and wood piles and a rich accumulation of ground litter.

Marmot habitat consists of large rock outcroppings, slides, and piles surrounded by mixed grass, forb, and shrub communities. If marmots exist adjacent to mined areas and the habitat requirements are supplied in the reclamation program, marmots will in all probability reestablish themselves.

Both the black-tailed and white-tailed prairie dogs occur in this region. Many people regard prairie dogs as undesirable species. As a result, prairie dogs were systematically eliminated from the range. However, resource managers must remember that prairie dogs, as a group, have been reduced to less than 5 percent of their former range and abundance (Linder and Hillman 1973). This and the fact that prairie dogs are virtually the sole food item of black-footed ferrets, makes the proper management of prairie dogs and important priority.

Extensive prairie dog colonies also provide habitat for a variety of other species, including insects, snakes, other small mammals, and burrowing owls (a species considered as "sensitive" by most wildlife agencies). Because of the ecological importance of prairie dogs, every effort should be made to maintain current population levels and distribution, particularly in areas being managed as range lands.

Before any prairie dog colony is disturbed, a thorough survey should be made to determine the status of all associated species, in particular the black-footed ferret. Details of the black-footed ferret survey techniques are presented in the section on ferrets.

Prairie dog habitat consists of short forb and grass communities with scattered sagebrush; white-tailed prairie dogs tolerate more sage and require more forb species than do black-tailed prairie dogs. Substrate characteristics include well-drained soils with water tables at least 4 m (12 to 13 ft) beneath the surface. The substrate should also be free of extensive impermeable rock strata to a depth of 3 to 4 m (10 to 14 ft).

Most prairie dog colonies exist on fine- to medium-textured alluvial soils, although colonies do exist on coarse glacial outwash material. This suggests that a rocky substrate is not in itself a significant limiting factor (Koford 1958). If prairie dog populations exist adjacent to or near a reclaimed site, they can be expected to repopulate the area when the vegetative components of their habitat are in place. Prairie dogs can be transplanted to new sites if desired (Garst 1962; Carpenter et al. 1969).

Detailed life history information on prairie dogs can be obtained from Koford (1958), Linder and Hillman (1973), and Clark (1977). An extensive prairie dog bibliography can be found in:

Hassien, F. 1976. Prairie Dog Biliography. USDI-BLM Tech. Note 279. 28p.

Porcupines require forested areas for much of their existence. They eat the inner bark of most conifers and many hardwoods, including alder and willow. During the spring and summer months, their diet includes a wide array of forbs and woody species. Protective cover includes brush piles and hollow logs, but rocky crevices in ledgers and talus slopes are preferred. Porcupines will generally find and populate suitable habitat.

Resource managers are often concerned with the damage porcupines can inflict upon conifer stands. This is usually exaggerated and probably of little concern to surface mining reclamation plans unless these call for extensive reforestation efforts. In the latter case, efforts may have to be made to prevent procupines from damaging seedlings and young trees.

Two species of aquatic rodents occur in this region, the muskrat and beaver. Both species require relatively stable year-round sources of fresh water containing sufficient depth and/or flow to keep from freezing solid during the winter.

Beaver eat the bark of many deciduous species, especially aspen, cottonwood, willow, birch, and alder. Summer foods consist of aquatic plants such as duckweed and waterlily roots. In spring, beaver will eat the young shoots, buds, and roots of a variety of grasses and herbs.

Beaver will repopulate an area when an abundant year-round food supply exists and if the waterway does not freeze solid. If the habitat exists as large, isolated impoundments, it may be necessary to transplant beaver to the new site. This should be determined with the cooperation of State wildlife management personnel and then only if sufficient habitat exists to support a viable population over many years. This will not be the case until many years after the reclamation work is completed.

Muskrats rely more on shallow water and aquatic vegetation for food and cover than do beaver. Cattails, bulrushes, sedges, and a variety of riparian herbaceous plants are consumed by muskrats. They will also eat new clover and other domestic species if they occur near water. Like beaver, muskrats will repopulate a watercourse once their habitat requirements are met and if the site is contiguous with existing populations. Isolated impoundments may have to have animals reintroduced, but this should only be done with the cooperation of State wildlife managers and then only if the habitat is sufficient to sustain a viable population indefinitely.

Because of their habit of feeding on agricultural crops and tunneling into banks and irrigation ditches, the introduction of muskrats to a new water system should be done only after considering all the potential effects. However, their presence can be used to advantage. For example, muskrats eat large amounts of aquatic shoreline vegetation, which can be important in maintaining openings along the shoreline for shorebirds and water fowl (Errington 1967).

Carnivorous Mammals

All of the mammalian predators in this region belong to the order Carnivora. They all prey on other animals and they occupy a wide variety of habitats. For some species, like the coyote, virtually any organic item can be eaten and virtually every terrestrial habitat can be occupied. But for species like the black-footed ferret, only a very specific habitat and food source can be utilized. Consequently, some species will require little or no specific consideration in the reclamation plan while others will demand a great deal of attention.

The following publications provide information about predators and predation:

Errington, P. 1967. Of Predation and Life. Iowa St. Univ. Press. 277p.

Ewer, R. 1973. The Carnivores. Cornell Univ. Press. 494p.

Mink. Mink are listed as small game or furbearers by State wildlife agencies and, consequently, any significant management efforts should be coordinated with State personnel.

The mink is a member of the weasel family. It can be encountered in many habitat types but will seldom venture far from open water. It will consume a variety of food items, including fish, mollusks, salamanders, frogs, birds, bird eggs, muskrats, field mice, cottontail rabbits, and almost any other item which it is capable of killing.

Because of its close association with open water, habitat management for this species should center on providing and maintaining an extensive riparian system with a diversity of plant communities and ample fresh water. All of these are necessary to support the diverse and abundant prey populations required by mink.

Mink can help in controlling potentialy detrimental species, such as muskrats and mice. If the reclamation site is contiguous with existing mink populations, they will repopulate the site naturally once the habitat requirements are met.

Otters. Otters are highly specialized members of the weasel family which require large bodies of open, fresh water.

They spend most of their time in water or along the shore and feed almost exclusively on fish and other aquatic species encountered in or near water, such as mollusks, crayfish, salamanders, frogs, and occasionally, young ducks.

Otters are uncommon throughout their range in North America and are protected by both State laws and by the Convention on International Trade in Endangered Species of World Fauna and Flora (CITESF). Because of their dependency on large bodies of undeveloped water rich in aquatic life, it is unlikely that this species will be encountered in any surface mining operation in this region.

Weasels. Weasels occupy a wide range of habitat types, extending from riparian to subalpine zones. They require abundant and diverse prey populations consisting of mice and other small mammals for their year-round food needs. Most weasels will also take young birds and eggs of ground-nesting species. Cover requirements include a moderately dense understory layer with micro-environments of broken terrain, brush and rock piles, rocky outcroppings, and dense stands of herbaceous and woody species.

Weasels are highly mobile and will repopulate an area when suitable habitat exists. They may play a beneficial role in controlling small mammal populations that may otherwise hinder plant growth. But, because of their small size, they can become prey items for other larger predators. Therefore, to attract weasels to a site to control rodents, there must be abundant escape cover for the weasels in the form of rock piles, brush piles, or broken ground surface. Weasels will benefit greatly from even small areas left in "wild" habitat, such as fencerows and odd field corners.

Skunks. Two species of skunks appear in this region, the striped skunk and spotted skunk. Of the two, the striped is the most common. Both are omnivorous, eating insects, grubs, berries, mice, lizards, frogs, grass, and occasionally carrion. The striped skunk spends more of its time in open fields and in riparian zones than does the spotted skunk, which can be found more often in brushy and arid country. The striped skunk will readily use dens of badgers, marmots, rabbits, and prairie dog. The spotted skunk will utilize rock piles, ledges, and crevices more often than burrows. Both species adapt well to human development and will often use buildings for shelter.

Skunks, like weasels, are highly beneficial because of their omnivorous food habits. They will usually reoccupy their range once their habitat is in place. Like the weasels, skunks can benefit from even small areas of land left "wild." Fencerows and odd field corners allowed to become brushy and drainages and riparian areas left ungrazed or uncultivated can provide valuable cover for these small predators.

Badgers. Badgers are animals of the grasslands and sagebrush country. Like the other small predators, badgers will eat a wide variety of animal matter. They make their own dens, and when digging for food items such as ground squirrels, they provide burrows used by other ground-dwelling species such as cottontail rabbits and burrowing owls.

When habitat requirements are met (abundant prey base), badgers will repopulate an area naturally.

Black-footed ferrets. Black-footed ferrets are probably the rarest mammals in North America. They are protected by the Endangered Species Act of 1973 and are listed with the International Union for the Conservation of Natural Resources. They are members of the weasel family and are approximately the same size as a mink. They appear to be confined to prairie dog towns, both white-tailed and black-tailed. It is estimated that prairie dog populations have been reduced by as much as 95 percent from their former range, and it can be assumed that ferrets have suffered a similar or even greater loss in numbers (Linder *et al*. 1973).

Until recently, many wildlife managers thought that ferrets were found only in association with black-tailed prairie dogs, but discoveries in 1981 in northwestern Wyoming have demonstrated that ferrets also exist in white-tailed prairie dog colonies. Four publications summarized the information available before the discoveries of the new population in Wyoming:

Henderson, F., P. Springer and R. Adrian. 1969. The Black-Footed Ferret in South Dakota. South Dakota Dept. Game, Fish and Parks. 38 p.

McNulty, F. 1971. Must They Die? New York. Doubleday and Co. 87 p.

Snow, C. 1972. Black-Footed Ferret, *Mustela nigripes*. USDI-BLM Tech. Note 168, 23 p.

Linder, R. and C. Hillman. 1973. Proceedings of the Black-Footed Ferret and Prairie Dog Workshop. South Dakota St. Univ., Brookings. 208 p.

Information on new publications concerning the Wyoming population can be obtained from the Black-Footed Ferret Coordinator with the Wyoming Game and Fish Department in Cheyenne, Wyoming.

Because of the endangered status of this species and its now proven association with white-tailed prairie dogs, the first priority of a wildlife manager is to determine the distribution of prairie dog towns and then determine the presence or absence of ferrets.

Prairie dog towns can be located with aerial reconnaissance, from aerial photos, ground survey, and by talking with local landowners and lease holders. Once prairie dog towns are located, a ferret survey must be conducted.

Based upon recent work with the Wyoming ferret population, two survey methods appear to work best. First, a ground reconnaissance of prairie dog towns should be conducted during winter immediately after fresh snowfalls. Ferret tracks look like mink tracks (Murie 1954), but unlike mink, they will enter and leave prairie dog burrows.

It is during the winter that ferrets are apt to construct "trenches" with the dirt dug from prairie dog holes. These trenches may extend 30 cm to nearly 8 m (1 to 25 ft) from the burrow entrance and be from 8 to 20 cm (3 to 7 in) wide. These trenches are not common, but their presence is strong evidence of ferret presence (Clark pers. comm.). All prairie dog colonies should be surveyed several times each winter and preferably after fresh snowfalls.

The second survey technique is best accomplished from June to September. During these months, night activity of ferrets appears to be at its greatest. Ferrets can best be located with the aid of spotlights producing at least 200,000 foot candles of illumination. These lights can be operated from 12-volt vehicle batteries while driving through prairie dog colonies or, in areas not accessible by vehicle, 12-volt batteries and spotlights can be carried in backpacks. Thorough surveys of each area should be conducted for at least two nights and preferably more.

Above-ground ferret activity peaks from 3 hours before sunrise to about 1 hour after sunrise. A lesser activity peak occurs shortly after sunset and continues for about 2 hours. Ferret eyes reflect a green color and their erratic up and down movements distinguish them from rabbits (pink reflection), which move more slowly and smoothly, and antelope, which also reflect a green color but are usually still or moving in smooth arcs. Ferrets can often be approached to within 20 to 50 m for positive identification.

During July and August, ferrets may be seen above ground anytime during the first 3 to 4 hours after sunrise, but the short time spent above ground and the sporadic nature of these activity periods do not lend themselves to successful surveying.

There is no other known method of determining the presence of ferrets in a prairie dog colony during the summer. Even when it is known that ferrets occur in a particular den, no visual clue exists at the surface and it is very easy for a reconnaissance team to complete a daylight survey and conclude that no ferrets exist.

If ferrets are located or even suspected of being in an area, the State wildlife managers and the regional U.S. Fish and Wildlife Service office should be notified immediately. A thorough survey will then have to be conducted, and this should be done either during the mid-June to early September period or during the winter months after fresh snowfall. State and Federal officials will be able to recommend personnel experienced in ferret survey procedures whose assistance should be obtained.

The difficulty of observing ferrets, even when they are known to occur in an area, cannot be overemphasized. Therefore, before any prairie dog population is disturbed, the site must be thoroughly surveyed for ferrets. This must include winter snow track searches and June to September nocturnal spotlight surveys. Negative results obtained from surveys taken during other times of the year should not be considered as final.

The only reasonable reclamation effort to aid ferrets must involve the establishment of a prairie dog colony on the site. This can best be accomplished by encouraging adjacent populations to expand into the new site. For this to succeed, the area will first have to be planted in a mixed shortgrass and forb community with some sagebrush. Second, the prairie dog colony will have to be protected from future control operations and from indiscriminate shooting.

Raccoons. Raccoons are recent invaders into much of the NRMGPR (Long 1965). They are very tolerant of human activity and readily adjust to human presence. Raccoons will commonly use abandoned buildings for shelter and solid waste disposal sites for foraging areas.

Normally, raccoons concentrate their activity in riparian areas. Their natural foods include crustaceans, amphibians, frogs, small snakes, insects, birds and bird eggs, and small mammals.

Diverse riparian habitat with sufficent food and cover (shrubby undergrowth, hollow trees, and brush piles) will usually be adequate to attract raccoons from adjacent populations. The greatest limiting factor in their range expansion is probably excess snow accumulations and weather so cold that streams and ponds freeze.

Coyotes. Coyotes are the most successful large predators in North America. They occupy virtually every terrestrial habitat and can eat an extremely wide range of food items (Sperry 1941). Coyotes require few special management procedures to survive. They are highly mobile and can be expected to occupy appropriate habitat as soon as it is available.

Coyotes can play an important role during the early stages of revegetation by consuming large numbers of insects and small mammals, all of which can inhibit early plant growth. Consequently, it may be important to prohibit the shooting of coyotes on and near the mine site for the first few growing seasons or until the vegetation has established itself.

Foxes. Three species of foxes may occur in portions of this region: the red fox, gray fox, and swift fox.

The red fox has one of the widest ranges of the large mammals in North America (Stains 1975). This suggests a high tolerance for human activity and development. The gray fox is more prevalent in warmer climates and areas of thick, brushy cover, while the red fox ranges northward into Canada and Alaska and favors forest edges and meadowlands. The status of the swift fox is poorly known in most of its range, but it appears to exist primarily on undisturbed land.

Although not listed as either threatened or endangered, most management agencies give the swift fox a "highly priority" management status.

Historically, the swift fox occurred in the semiarid shortgrass habitats of the United States from New Mexico north to Canada (Stains 1975). It should not be confused with the kit fox, which occupies the more arid regions west and south of the range of the swift fox (Thornton et al. 1975; Snow 1973).

The major food items taken by the swift fox include small mammals (pocket mice, kangaroo rats, ground squirrels, cottontail rabbits, and jackrabbits), birds, lizards, snakes, and insects (Cutter 1958; Kilgore 1969). The literature contains contradictory information concerning the adaptability of the swift fox to human presence and activity, but Snow (1973) concludes that habitat loss and indiscriminate "predator control practices" impose the greatest limiting factor on this species. However, Kilgore (1969) reported that nearly one-half of the 35 dens he found in Oklahoma were in cultivated fields.

Recent reports of this species in North Dakota (Pfeifer et al. 1970) and Wyoming (Floyed et al. 1981) suggest that the species is making a modest comeback in the northern plains states. Consequently, resource managers should conduct pre-mining inventories for this species.

The survey should consist of questioning area trappers, hunters, and ranchers and conducting den surveys and track surveys when fresh snow exists. Dens are used year-round for shelter during inclement weather and for rearing young from April through July. If swift foxes are located and their dens are in areas proposed for mining, attempts should be made to relocate them to habitat that will remain undisturbed. This should only be undertaken with the cooperation of State wildlife personnel and only during the non-breeding portion of the year (September to late January). Trapped individuals should be taken to habitat as similar to their original habitat as possible. This should include abundant food, cover, and numerous existing burrows which the swift fox can renovate for its own use.

If an active den (one with pups) is encountered in an area marked for destruction, the area should not be disturbed until after the whelping and rearing phases are completed. Then the adults and the pups should be live-trapped and taken to a new location, again one with numerous unoccupied burrows and abundant food.

Reclamation efforts which will benefit the swift fox are similar to those benefiting most large mammals native to the shortgrass-sagebrush areas of the northern Great Plains region. These include the establishment of mixed plant communities with diverse and abundant prey species.

Bobcats. Bobcats are classified in most areas as furbearers and thereby are subject to State laws. They occur in a wide range of habitat types, but prefer a mosaic of rough brushy and wooded lands interspersed with rock outcroppings, cliffs, ravines, and gullies.

Their food preferences are similar to those of coyotes, but bobcats depend less on carrion than coyotes.

The large home range (15 to over 170 square km) (Guggisberg 1975) and the natural mobility of bobcats assure that this species will be able to move out of the disturbed area. To prevent a permanent loss of habitat, the reclamation plan should provide a mixed habitat of brushy and wooded areas with rough terrain interspersed throughout. This, coupled with an eventual buildup of prey, should attract bobcats back to their original habitat provided nearby populations exist in sufficient numbers to repopulate new sites.

Young (1958) reviews basic habitat affinities, food habits, and reproductive data for the bobcats.

Cougars. Cougars have legal protection as game animals in the States where it still occurs and is considered a "high priority" species by wildlife agencies.

Historically, cougars range from coast to coast and from Canada to the tip of South America. Presently, in the United States they occur only in the remote portions of Florida and the Southeast and in some of the remaining rugged mountains of the Western United States (Russell 1978; Young et al. 1946; Hornacker 1969, 1970). Cougars will probably not be encountered in most proposed coal mining areas. But, if they do occur, every effort should be made to manage the operations and reclaim the site for the benefit of this rare predator.

Cougars require large tracts of wild and relatively undisturbed land containing an abundant large mammal population on which it can pry. Winter is critical period in a cougar's life cycle, when it must be able to hunt large ungulates. Since cougars have a low tolerance for humans they will usually not hunt ungulates wintering in the vicinity of humans. Therefore, if the reclaimed area is to provide wintering habitat for substantial numbers of big game animals and if cougars are present in the areas, every effort should be made to keep human activity as far away from these sites as possible.

Black Bears. Black bears were once common in most of the mountains and forested areas of this region. Their tolerance of human activity has often brought them into conflict with man, particularly when garbage was left in the open for bears to feed upon (Jonkel 1978).

If black bears are present in the vicinity of the proposed mine, sanitation will be of major importance. All refuse should be contained in heavy, covered metal facilities and removed from the site at least once a week and preferably twice a week. Personnel should be prohibited from engaging in any activity which would attract bears to the area. This includes prohibiting feeding of bears and prohibiting the accumulation of foodstuffs and containers.

Reclamation goals which will benefit black bears include those which will provide wooded cover, diverse forb and woody understory cover, and diverse small mammal populations. These objectives can be achieved only after years of undisturbed plant growth and succession. The area should also remain relatively free of permanent human activity.

Big Game Mammals

Pronghorn Antelope. Pronghorn antelope are the only members of the family Antilocapridae, a family indigenous to North America. Historically, the pronghorn occupied the short- and medium-grass prairies from southern Canada to central Mexico. It has been speculated (Nelson 1925) that the pronghorn population in North America once numbered over 40 million, exceeding even the bison. But with the settlement of the continent, pronghorn numbers began a rapid decline. By the early part of this century, only an estimated 13,000 antelope remained in the United States (Hoover et al. 1959). This decline has been attributed to habitat loss brought on by changing land use patterns, competition with livestock, and extensive market hunting and poaching (Yoakum 1968). By the 1920's, the plight of the antelope was recognized and intensive management efforts were initiated by State, Federal and private wildlife groups. Today, an estimated 400,000 to 500,000 antelope exist in the United States. Although representing only about 1 percent of their historic numbers, today's antelope populations are healthy, viable, and responding well to management efforts.

The success with which the antelope population rebounded indicates the resilience of this species under sound management programs. Major elements in a successful management program are adequate habitat, year-round access to this habitat, available surface water, and controlled harvest. The following publications will assist the manager:

Yoakum J. 1967. Literature of the American Pronghorn Antelope. USDI-BLM. Reno, Nev. 82 p.

________. 1978. Pronghorn. In: Schmidt, J. and D. Gilbert (eds.). Big Game of North America. Harrisburg, Penn. p. 103-121.

Sundstrum, C., G. Hepworth, and K. Diem. 1973. Abundance, Distribution and Food Habits of the Pronghorn. Wyoming Game and Fish Dept. Bull. No. 12. 61 p.

Yoakum, J. 1974. Pronghorn Habitat Requirements for Sagebrush-Grasslands. Proc. Biennial Antelope States Workshop 6: 16-25.

Pronghorn antelope habitat is typified by the low rolling and open, expansive plains of the Northern Great Plains region. Prime habitat usually exists between 1,200 and 1,830 m (4,000 to 6,000 ft) elevation. Most of this region receives snowfall, but areas where accumulations exceed 25 to 30 cm (10 to 12 in) may prove unsuitable for antelope (Yoakum 1978).

Yoakum (1978) has outlined the habitat characteristics of preferred antelope range:

Ground cover should average 50 percent living and 50 percent non-living vegetation.

Vegetative composition should average 40-60 percent grass, 10-30 percent forbs, and 5-20 percent browse.

The plant community should contain at least 5-10 species of grasses, 20-40 species of forbs, and 5-10 species of shrubs.

Rangelands with these components occurring in mosaic patterns are preferred to extensive monotypic communities.

Vegetation on preferred range averages 38 cm (15 in) in height. Rangelands with vegetation exceeding 61 cm (24 in) are less preferred, and lands with vegetation over 75 cm (30 in) are used infrequently. Antelope may occasionally use areas with taller vegetation such as saltbush for forage, and they will pass through such areas when necessary, but they prefer predominately short cover.

The publication, "Rehabilitation of Western Wildlife Habitat: A Review" (USFW/OBS-78/86) reviews antelope habitat requirements and forage preferences. Antelope summer food preferences (percent composition) in Montana were 33 percent browse, 60 percent forbs, and 2.5 percent grasses, with other forms making up the rest of the diet. Fall antelope diets were 77 percent browse, 21 percent forbs, and 3 percent grasses. Winter diets were composed of 80 percent browse, 10 percent forbs, and 2 percent grasses.

These combinations are typified by subclimax conditions. Historically, these conditions were created by wildfires and seasonal grazing by other herbivores such as bison, elk, and deer. These factors kept the plant communities in a state of flux and benefited the mixed shrub, forb, and grass mosaic patterns. Percentages of the three major vegetative elements should be kept in line with the figures presented earlier. By utilizing appropriate seed mixtures during revegetation.

Preferred browse species include big sagebrush, black sagebrush, Utah juniper, atriplex, rabbitbrush and greasewood. Favored grasses include the grama and buffalo grasses. Antelope also prefer alfalfa and can become a nuisance if allowed to congregate in hay meadows.

The differences previously noted in seasonal food preferences should be kept in mind when seeding a reclaimed site. If the area is to supply summer range, the seed composition should be different from that intended for winter range. The choice will be based in part upon which element of local antelope habitat is in shortest supply and which habitat type will be best suited to the site in question.

In this northern region, winter range is usually in shortest supply and is the preferred reclamation goal. This will necessitate a greater density of browse species than a seed mixture intended to supply summer range.

The literature reports differences in antelope forage preferences. It appears that in areas where average snow accumulation is low, grasses represent a larger portion of the diet than in areas where snow accumulations are greater; in the latter, browse species make up a greater portion of the winter diet. This may not so much reflect the food preferences of antelope as the proportional availability of the various species. Sagebrush will be available to antelope long after the grasses have been covered by snow. Browse species may not be preferred, but they are available. As managers charged with choosing the seed mixture for a reclamation project, we must use the species which will remain available to antelope. Where snow accumulations often exceed 25 to 30 cm (10 to 12 in), tall-growing browse species should be favored. They may not be the preferred species, but they must continue to be the available species if antelope are to survive.

The availability of surface water plays an important role in determining range utilization by antelope. The following guidelines are adapted from Yoakum (1978):

Water should be available every 1.6 to 8 km (1 to 5 mi) depending on range conditions and accessibility.

Water should be available every season, except when snow is present.

Water catchment basins can be designed specifically for big game use where naturally occurring surface water is not available. Most State wildlife management agencies have preferred designs for these basins. If designs are not available, Giles (1969; p. 193-202) provides several designs suited to conditions in the West. Yoakum (1978; p. 119) provides the plans for a water catchment basin designed by the Wyoming Game and Fish Department specifically for antelope. Bird (1977) presents designs for wildlife water basins developed for the BLM in New Mexico.

Antelope are poor jumpers and consequently have a difficult time negotiating many of the fences on western rangelands. Such barriers can become a significant mortality factor if they keep the antelope from reaching water, winter and summer range, or other important habitat components.

Specific fencing recommendations have resulted from numerous studies conducted throughout antelope range. Anderson (1980) reviews different designs the BLM uses to ensure free passage for antelope. Yoakum (1979) lists these recommendations for constructing fences on antelope range:

Woven wire fences are generally barriers to antelope; therefore, their construction on antelope range should be discouraged unless the objective is to keep antelope off specific range.

Avoid the construction of any fences not absolutely necessary to the total management effort.

Antelope "passes" can be constructed in areas of heavy antelope use. These consist of cattle guard-like passages measuring about 122 cm (48 in) wide (between fence posts). These passes work best when built in fence corners where the fence funnels antelope to the opening. These generally do not work as well as the fence designs described below, but they can work in specific locations.

Three-strand fences work the best for allowing antelope passage. These should be built in the following design criteria: a) Bottom wire at least 41 cm (16 in) above the ground and, because antelope crawl under fences, the bottom strand should be barbless; b) the next wire should be 25 cm (10 in) above the bottom strand; c) the third or top wire should be 91 cm (36 in) above ground; d) no stays should be placed between posts and the wires should not be overly tight; e) fence crossings on important antelope movement routes should be fitted with several consecutive "lay down panels"; f) alternatives to "lay down panels" are constructing the fence so that the two bottom strands can be lifted to the top strand or so that the bottom strand can be placed on the ground and the second strand can be lifted to the top strand.

Scotter (1980) reviews the many concepts and techniques currently in use in the management of ungulate habitat in the Western United States.

Mule deer. Mule deer occur in most rural areas of the NRMGPR that still contain some rough country, undeveloped stream bottoms, and draws which provide cover and forage diversity. Throughout their range, nearly 0.5 million mule deer are harvested annually, making them one of the most popular big game animals in North America. Consequently, they have received much attention from wildlife management agencies and this has resulted in an abundance of management information for nearly every portion of their range.

The following publications review life history and management information for the mule deer:

Kerr, R. 1979. Mule Deer Habitat Guidelines. USDI-BLM Tech. Note 336, 61 p.

Wallmo, O. 1978. Mule and Black-tailed Deer. In: Schmidt, J. and D. Gilbert (eds.). Big Game of North America. Harrisburg, Penn. Stackpole Books. p. 31-21.

Taylor, W. (ed.). 1956. The Deer of North America. Harrisburg, Penn. Stackpole Books. 668 p.

Scotter, G. 1980. Management of Wild Ungulate Habitat in the Western United States and Canada: A Review. J. Range Mgmt. 33(1):16-27.

Mule deer are adaptable, responding well to management efforts. They will tolerate moderate levels of human activity as long as important habitats (usually winter range) are present and accessible.

Since the range of the mule deer is so extensive and includes such wide variations in habitat, management efforts should be closely coordinated with State wildlife biologists. Only brief management guidelines will be considered in this report.

Mule deer are considered to be "intermediate feeders" because they adapt well to a wide range of forage types ranging from grasses to woody plants. The list of items eaten by mule deer seems limited only by the efforts of the investigator (Wallmo 1978). Thus, variety may be the most important factor in the year-round mule deer diet.

A brief seasonal dietary summary follows. Spring sees the largest occurrence of grasses in the mule deer diet. At this time, new growth provides a succulent high protein alternative to the usually restricted winter diet. As summer begins, forbs constitute a larger fraction of the diet, while the use of grasses drops in importance; new shrub growth increases to second or third position.

Fall usually marks the transition to shrubby vegetation while forbs drop to second place. Winter sees shrubs and trees making up 75 percent or more of the mule deer's diet. During this season, the relatively high protein value of woody plants makes them important. Although grasses and forbs will be taken whenever available, their relatively low winter protein content will usually not ensure deer survival if additional sources of protein are not available. The importance of high-protein winter foods is dramatized by the fact that countless mule deer have "starved" to death in and around ranch haystacks, their stomachs full of low protein, high carbohydrate foods.

Some of the major woody species eaten by mule deer are: bitterbrush, mountain mahogany, big sagebrush, serviceberry, juniper, wild cherry, oaks, aspen and cliffrose. Some of the important grasses include bluegrass, wheatgrass, brome grass, the fescus, and ryegrass.

This briefly summarizes the varied nutritional requirements of the mule deer and points out the irony of the apparent catholic food habits of this species; on one hand, it appears that mule deer will eat almost anything and consequently have no specific food requirements, when in fact the wide seasonal variation is itself a requirement. Thus, the reclamation effort must be aimed at providing a varied habitat type with diverse species composition. The mere presence of vegetational variety does not insure the survival of a mule deer population. Other factors also can have a detrimental effect on mule deer populations. These include cover, water, and freedom from human disturbance. The latter can include everything from protection from poaching to freedom from harassment on winter range.

In this region, cover is provided by broken terrain as well as by tall vegetation (riparian and forest communities). Appropriate features can be provided during the reclamation effort by including topographic irregularities, mine-end high walls (these should not extend for more than 500 m (540 yd) without a break of sufficient size to allow ungulates to pass through the wall), and watercourses in the landscape. Although, the growth of suitable cover may require many years, this should not discourage the manager from initiating these efforts.

Cover has three major functions for deer: it provides a place in which to hide, a cold weather thermal insulation area, and a warm weather shade area. Some or all of these elements may be provided by topographic features, but the addition of appropriate vegetation can provide a larger and more varied assortment of options for the deer population.

Water can also be a limiting factor in the arid regions of the West. Although no one formula exists which can predict the distribution of available water necessary to sustain a deer population, most researchers recommend that water sources be no more than 3.3 to 5 km (2 to 3 mi) apart. Lack of water can reduce the carrying capacity of the range and it can cause concentrations of all ungulates, wild and domestic alike, around the available water. This can result in forage depletion, increased stress levels, trampling and muddying of water holes, and inevitable die-offs.

If water troughs are provided for wildlife, they should not exceed 50 cm (20 in.) in height. If they do, fawns will not be able to reach over the edge to obtain water. Bird (1977) provides some guidelines on water basin construction for wildlife, as do Kerr (1979) and Giles (1969, p. 190-197).

Disturbance by humans includes harassment on winter range by recreationists, poaching year-round, and construction of roads and fences across movement corridors. Predicting the effects of roads and fences can be done by identifying deer movement patterns.

This includes locating the major components of year-round range and avoiding crossing these locations or the routes between them. These problems can be avoided if, during the reclamation effort, the important components are placed in close proximity to one another and not separated by major roads and fence lines.

Mule deer can generally maneuver fences better than pronghorn antelope, but some precautions must be taken when constructing fences on deer range. These include keeping the fence height below 106 cm (42 in) on level ground. As the slope increases (perpendicular to fence line) and/or as snow accumulations increase, a 106-cm fence becomes a greater barrier. Under these conditions, fences should not exceed 50 cm or should be constructed to allow the top two wires to be lowered so the overall height does not exceed 50 cm. Anderson (1980) reviews fence plans designed specifically to facilitate big game movements.

If a proposed mine site overlaps critical deer range (winter areas), efforts should be made to improve or create nearby wintering sites to accommodate the displaced individuals. This can be accomplished through a variety of range improvement practices as outlined in Kerr (1979). Again, an effort must be made to insure that these areas are accessible to the displaced deer (i.e., high fences and major roadways should not dissect the access route) and that they remain free of human disturbance.

White-Tailed Deer. Historically, white-tailed deer occurred throughout most of the lower elevations of this region. Recently, they have been eliminated or greatly reduced in numbers and now can be found only in selected areas. The U.S. Fish and Wildlife publication (FWS/OBS-78/86) reviews habitat requirements for the white-tailed deer. Other sources of management information include the following publications:

Taylor, W. (ed). 1956. The Deer of North America. Harrisburg, Pa. Stackpole Books. 668 p.

Halls, L. 1978. White-tailed Deer. In: Schmidt, J. and D. Gilbert (eds.). Big Game of North America. Harrisburg, Pa. Stackpole Books. p. 43-65.

Scotter, G. 1980. Management of Wild Ungulate Habitat in the Western United States and Canada: A Review. J. Rng. Mgmt. 33(1):16-27.

White-tailed deer prefer forest habitat types interspersed with bunch grasses and shrubs and agricultural lands. Preferred forest habitat types include aspen, ponderosa pine/Douglas-fir, and in higher elevations, Douglas-fir/Englemann spruce conifer types. Cottonwood-greasewood types are also heavily used along river bottoms. White-tailed deer appear to require a greater amount of vegetative cover than mule deer.

Cover preferences are also reflected in the food requirements of the white-tailed deer. The summer diet includes forbs and browse, while browse increases in importance in the fall and becomes almost the sole food item in the winter. Grasses are consumed primarily in the spring, but still follow forbs and browse in importance (USFW/OBS 1978). The greater the variety and availability of preferred plants, the greater are the chances for the white-tailed deer to thrive.

Because of the woody and forested habitat requirement, it may take decades for a reclaimed site to become suitable cover for white-tailed deer. But if adequate cover exists adjacent to a mine site, the reclamation effort can provide forb and grass meadows that have immediate value to foraging deer.

Because of the habitat preferences of the white-tailed deer, water is usually not as great a limiting factor as it is with the other ungulates of this region. However, whenever possible, efforts should be made to provide surface water.

White-tailed deer are subject to other limiting factors, including restricted movements due to fences and roadways, harrassment from people and pets, and poaching. Care must be taken to minimize these factors.

Moose. The moose, North America's largest member of the deer family, is confined to the cooler, higher elevations of the northern Rocky Mountain States. Franzmann (1978) and FWS/OBS-78/86 (1978) both emphasize the importance of browse species in the year-round diet of the moose. In the northern Rocky Mountain states, willows, dogwood, and firs are the predominant browse species, while aquatic submergents play an important role during summer. Houston (1968) provides detailed ecological information about the moose population in the Jackson Hole region of northwestern Wyoming, and Peterson (1955) presents detailed life history information for the species throughout most of its North American range.

Several features appear to dominate moose habitat requirements: riparian zones with willows or willow-conifer complexes, upland aspen and conifer communities with a willow-brush understory, upland mountain brush communities (chokecherry and bitterbrush), and conifer forests (Douglas-fir and/or spruce-fir stands).

Because of the unique habitat requirements of the moose, it is unlikely that mining activity will directly disturb anything but limited areas of winter range. Consequently, most reclamation efforts aimed at restoring moose habitat should follow the recommendation for riparian habitat.

American Elk. The elk was historically the most widely distributed member of the deer family on this continent. It extended from coast to coast and from Mexico to Alaska. It occupied arid deserts, hardwood forests, coniferous forests, and grasslands. Today, it exists in only a small percentage of its former range and is resricted to much less diverse habitats.

The following publications present information ranging from site-specific ecological data to species-wide natural history information:

Cole, G. 1969. The Elk of Grand Teton and Southern Yellowstone National Parks. Research Report GRTE-N-1. Nat. Part Service. 192 p.

Boyce, M. and L. Hayden-Wing (eds.). 1979. North American Elk: Ecology, Behavior and Management. Laramie, Univ. of Wyoming. 294 p.

Boyd, R. 1978. American Elk. In: Big Game of North America. Schmidt, J. and D. Gilbert (eds.). Harrisburg, Pa. Stackpole Books. 494 p.

Thomas, J. and D. Toweill (eds.). 1982. Elk of North America. Harrisburg, Pa. Stackpole Books. 698 p.

Like all of the ungulates, elk require different habitats during different times of the year. The habitat must contain cover (security and thermal) as well as forage sites. These entities must be provided at the seasons when they are required and in accessible locations.

USFWS/OBS-78/86 (1978) provides a brief review of habitat preferences and food habits. Elk are primarily grazers, with grass making up as much as two-thirds of their annual diet, browse species making up about one-quarter, and forbs providing the remainder. Forbs are used heavily during the summer, and browse species are used extensively on winter range. Kufeld (1973) reviews the plants eaten by the Rocky Mountain elk. This list provides an excellent guide to the selection of plants to be used in reclamation work.

One of the major prerequisites for good elk habitat is large expanses of unbroken cover providing concealment from human activity (Lyon et al. 1982). Consequently, most major elk populations today are closely associated with the mountainous and forested areas of the western United States (Skovlin 1982). These are the only remaining areas where rugged terrain and heavy forest cover provide the necessary barriers between the elk and human activity.

Ward (1976) concludes from his observations in Wyoming that in addition to the visual barrier, a minimum distance of 0.8 km (0.5 mi) must also exist between the disturbance and the elk. Where barriers are poor or do not exist, the distance may have to be increased to as much as 3.2 to 6.4 km (2 to 4 mi) (Lyon et al. 1982).

Thus depending on the terrain and cover, mining acitivity will have to be from 0.8 to over 6.5 km (0.5 to 4 mi) from occupied elk summer range to have minimal impact.

Skovlin (1982, p. 397) presents a checklist showing elk habitat requirements and the most frequent problems. Most stem from human-induced situations and can be solved only with sound managerial intervention. The most common problems involve availability and quality of winter range, and this is also where most mining-elk conflicts will occur.

If mining is to occur on or near winter range, State wildlife managers should be consulted before any mitigation work is undertaken. The primary points to remember are the importance of large blocks of disturbance-free range and of adequate winter forage in a mixture of grasses (wheatgrass, needlegrass, bluegrass, smooth brome, and fescue) and browse species (serviceberry, big sagebrush, juniper, and Douglas-fir). Last, winter range must be readily accessible to the elk; permanent, year-round human activity sites should not occur on important migration routes.

With the possible exception of disturbance-free areas and available water, summer range is generally not in short supply in this region (Boyd 1978). If mining is proposed on occupied summer range, additional summer habitat will have to be provided on adjacent sites or the manager can expect the loss of that segment of the elk population. Skovlin (1982) sites numerous studies which indicate that at least during the summer and fall months, elk are seldom found more than 0.5 to 0.8 km (03. to 0.5 mi) from surface water. If surface water does not occur at this distance, water-holding structures should be included in the reclamation plan. These can be earthen holding dams which can be filled with either runoff or well water. Bird (1977), Kerr (1979) and Giles (1969, p. 190-197) all provide guidelines for construction of water-holding structures beneficial to ungulates.

Bighorn Sheep. Bighorn Sheep were once widely distributed throughout the rugged, rocky terrain of the western United States. The current population of about 45,000 represents less than 5 percent of the pre-settlement population, and at least one subspecies, the Badlands or Audubon's bighorn, is now extinct (Wishart 1978). Initial population declines were attributed to overharvesting, introduction of exotic diseases and parasites (from domestic sheep), and habitat loss. Today, most management efforts are aimed at disease reduction and habitat protection, maintenance, and enhancement (Wishart 1978).

Geist (1971) provides the most recent account of bighorn sheep behavior and ecology, while other works (Buechner 1960, Cowan 1940) review the older literature. Two other studies (Hones et al. 1942, Smith 1954) provide site-specific studies for Wyoming and Idaho, respectively.

Several features stand out when decribing bighorn sheep habitat selection. First, bighorns are closely associated with rugged, rocky terrain, seldom venturing more than 100 m from cliffs or other escape cover. Second, they seldom enter heavy timber, and third, they avoid crossing large expanses of unbroken open country during their migrations between summer and winter range.

Summer range usually extends high into the subalpine and alpine zones, while winter range may extend to the lower limits of large cliffs and other escape habitat.

Bighorn sheep eat a variety of plants, but grasses are the single most important year-round food group. Second in importance are the browse species, which are eaten mostly during the winter. Of these, big sagebrush is the most important.

It is unlikely that bighorn sheep will be encountered on or near any proposed mine sites. If they are, State wildlife managers should be notified and all management decisions coordinated with them.

Bighorn sheep can also be affected if their migration routes are disturbed. This species does not readily adapt to new routes, and every effort should be made to insure that existing routes are not disturbed. This is particularly important in the fall when the movement from vast summer range must be completed to very specific and often isolated winter range. Once barred from their historic route, sheep are not likely to locate the winter range via a significantly different route.

The spring movement from localized winter range to the much more widespread summer range can usually be completed, even if the bighorn sheep are forced to deviate significantly (Geist 1971).

Similarly, bighorns apparently pass on knowledge of migration routes and home ranges from generation to generation; if denied these sites, for whatever reason, this knowledge will not be passed on to the next generation. Consequently, prime winter range--range historically used by bighorns--may remain empty because the sheep do not "know" of its whereabouts.

Last, bighorns suffer severely from competition with domestic livestock as well as from elk and deer. This is particularly true on winter range where resources are often in shortest supply. If the reclamation plan calls for establishing bighorn sheep winter range (or enhancing existing range), every effort should be made to minimize this type of competition. Domestic stock should be kept off all big game winter range and where bighorns and other big game utilize the same range, every effort should be made to enhance the site.

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RECLAMATION PLANNING AND REGULATION

PROBLEMS IN RECLAMATION PLANNING AND DESIGN

by

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INTRODUCTION

The planning and design of reclamation programs have progressed immensely since passage of the first in-depth State reclamation laws during the 1970s. Early reclamation efforts emphasized spoils reshaping and seeding with agricultural species. Reclamation programs today call for re-contouring spoils to original watershed topography, applying subsoil and topsoil, and seeding with various mixtures of native species. In addition, a modern reclamation program is concerned about hydrologic properties of the mined area, soil erosion, and wildlife habitat, as well as air and water quality. In this paper, reclamation planning utilizing "state-of-the-art" technology will be reviewed, and problems inherent in the rules and guidelines with respect to application of today's knowledge will be discussed. The report does not address the numerous premining tasks required of today's mineral extraction industry.

DEFINITIONS

A design is a mental image, while a plan is a draft or representation (as a map). By law, the reclamation plan must be incorporated into the permit application, and this requires a design or concept prior to formulation. The mental image of vegetation, soil, and water parameters, if it encompasses all postmining activities, may be termed a reclamation design. It must be translated into a reclamation plan if the design is to become a reality.

Establishing vegetation on minesoils is not reclamation. Unfortunately, many so-called reclamation plans are little more than revegetation programs, even though they may require spoil reshaping as well as plant seeding. Reclamation includes all aspects of the environment; it is not restricted to soils and vegetation. Although the disturbed area cannot be returned to its exact premining condition, it can be rehabilitated. It can be returned to a useful function in the ecosystem of which it is a part. Even mining wastes from open pit or underground hard rock mines can be returned to useful, productive states if an adequate reclamation plan is developed. In all cases, however, the most economical means of attaining the reclamation goals is to develop a suitable reclamation plan prior to actual land disturbance.

TRADITIONAL MINING CONCEPT

The early history of mining in North America and Europe illustrates what is referred to as the "traditional mining concept." It is equivalent to the slash-and-burn technique of agriculture as practiced by primitive tribes in equatorial regions of the world. The ecosystem is sacrificed for an alternate land use--agricultural production in the case of the slash-and-burn technology, or mining in the case of the traditional mining concept. After agricultural productivity drops or mine output diminishes, the ecosystem is allowed to repair itself without any help from man.

Early mining within the context of this philosophy envisioned mineral extraction as an ultimate land use. The mining decision was based upon the cost of exploration, extraction, conversion, marketing, and the price that the product would bring. Extraction, including all phases of the mining activity, was the land use. Mined areas were assumed to be a semipermanent part of the landscape if their future use was even considered.

This philosophy no longer exists in our society. Our growing population, our need for agricultural productivity, and our desire for recreational lands have forced discontinuation of these older mining practices. Laws have been enacted to prevent the widespread abuse of the land, and reclamation is now an integral part of mining. Recent legislation treats mining, especially strip mining, as a temporary land use.

MODERN MINING CONCEPT

In recent years, society has come to recognize the value of land as a renewable resource and the temporary nature of mining. This basic philosophical change reached its zenith in the United States with the passage of the Federal Surface Mining Control and Reclamation Act of 1977. Although some people question the wording in parts of this law, few take exception to the basic philosophical attitude it reflects: the preservation of the renewable environmental resource disrupted by mining.

Prior to enactment of modern reclamation laws, the mining company had only to investigate potential mine sites to determine the extent of a resource and research the market to arrive at an accurate estimate of profits. Today, the mining company must perform the same tasks but with the additional expense of maintaining the environmental quality of the mined area. The problem, therefore, is to identify, as accurately as possible, the real and/or emotional values that constitute environmental quality and incorporate them into the postmining, more permanent land use to be established on the mined site. This can most easily be accomplished by inventorying the environmental amenities of the site prior to disturbance and determining which of these resources will be altered by mining. The optimum mining plan will maximize mine output and minimize environmental loss at the most desirable benefit/cost figure. In the field of mineral extraction today the fusion of mining and reclamation into one operational program is the most desirable means of achieving this goal (Fig. 1).

PREMINING DECISIONS AND ACTIONS

Both Federal and State regulatory programs require that an application for a permit to mine coal contain a plethora of environmental information about the proposed mine site and the postmining land use. A data acquisition program has been designed to provide information about the real (e.g., physical, chemical, biologic, hydrologic) values that constitute the land resource. The methods and procedures for acquiring this information are stated in various agency guidelines. The purpose of these inventories is to define the environmental amenities that will be affected by the mining activity. This, together with the postmining land use, permit an easier and more rapid reestablishment of these environmental values after mining.

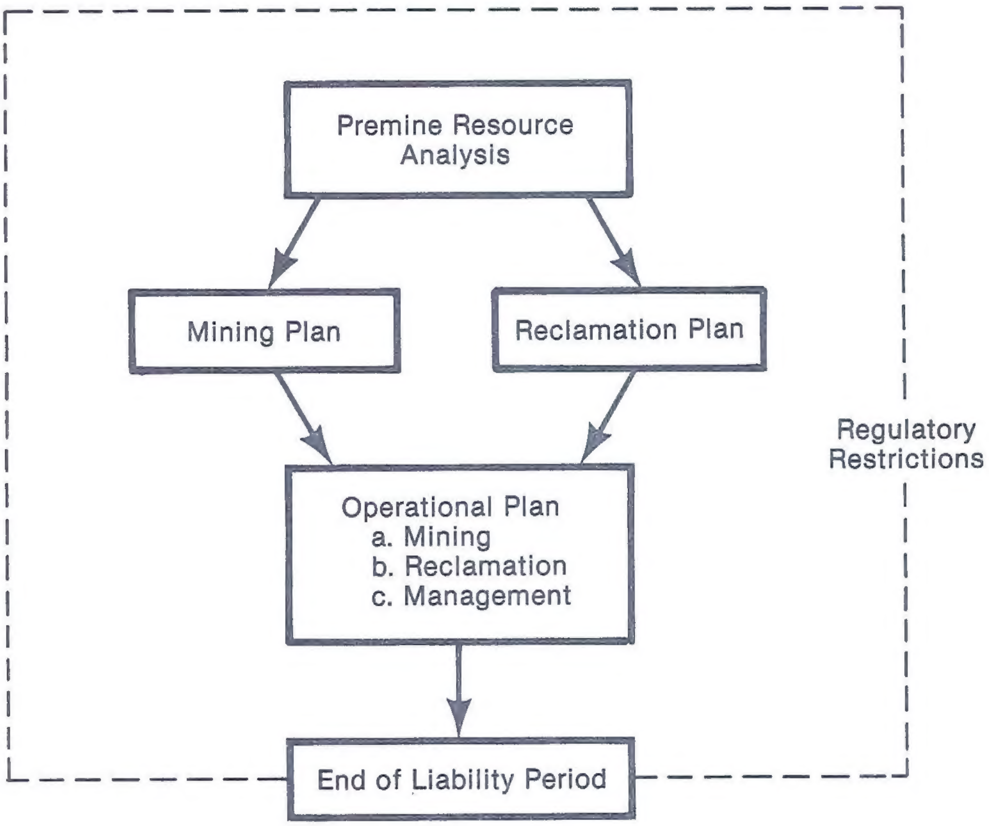

Figure 1. Development of reclamation program (adapted from Cull 1981).

Premining Inventory

The soil, geologic, vegetative, hydrologic, and wildlife parameters to be measured and described in the premining inventory are stated in Federal and State regulations and guidelines. Soil and geologic descriptions establish topsoil and subsoil availability or the need for alternate surface materials. Vegetative descriptions determine what types and kinds of plant communities are present prior to disturbance and guide plant species selection for the postmining landscape. Aquifer and surface water characteristics are pertinent to the ultimate land use decision and attaining reclamation goals. Wildlife inventories and use patterns complement the previous categories. Animals, like vegetation, are assets and a reflection of the productivity of the land resource.

Soil surveys and overburden analyses are useful in delineating the optimum reapplication of soil materials to mined lands. This practice is now an accepted segment of the premining resource analysis. Direct lift subsoiling and topsoiling are practiced at many Western mines. The identification of poor-quality surficial soils or overburden permits their segregation and the substitution of better materials for plant growth.

Vegetation native to the Great Plains is the result of thousands of years of plant evolution; thus, the plants growing on these rangelands are well adapted to their environment. Because these species are genetically adapted to this semiarid region, they are the most appropriate for the revegetation portion of the reclamation program. Collecting data describing the various plant communities is a valuable asset to the postmine reclamation program. Premining vegetation inventories emphasize identification of native plant communities and the species composition of these assemblages. Delineating plant communities is subjective, however, and data collection may become an exercise in ecological measurement rather than mine-site vegetation description. Transition zones between communities must be recognized as such, and time and money must not be wasted on descriptions of ecotones between plant groupings.

Describing the quantity and quality of groundwater flows is expensive and a still-emerging science. Because aquifers are out of sight they often receive only cursory attention. Nevertheless, these parameters are among the most important in defining the effects of mining on the subsurface hydrologic resource. Technology for adequately assessing the influence of mine-site aquifers on vegetation, downstream groundwater quantity and quality, livestock water availability, and above-ground stream flows is presently inadequate.

Surface water drainages are visible, more easily measured, and have consequently received much attention. Flows, quality, and drainage patterns are carefully noted and inventoried in the environmental assessment of the proposed mine site. The relationships between surface water and plant species development and abundance have been documented. The distribution of livestock and wildlife with respect to surface water has also been researched. As pointed out, the relationships between ground and surface water are less well known.

Postmining Land Use

The postmining land use influences all activities associated with the reclamation and mining plans. Leathers (1980) proposed three postmining options: 1) restore land and water resources to approximate premining use; 2) restore land to greater value or use; and 3) create sacrifice areas in which no reclamation is practiced. Present coal strip mine reclamation law requires that the first or second alternative be applied.

At this time some Western States allow landowner input into the ultimate land use decision. Other States allow almost no landowner involvement in this critical decision. Rangeland for livestock grazing and/or wildlife habitat is generally the approved postmining land use. However, as regulatory agencies gain experience and recognize the value of landowner input, greater initiative will be granted to the owner of the surface rights to influence the postmining land use decision. For example, only 5 years ago in Montana a landowner was unable to have the mining company create stock-watering impoundments on his land during mining, but today this idea meets with less opposition from the regulatory agency. Within a few years ranchers may be able to anticipate such marginal benefits from mining activities. Care must be exercised, however, to distinguish between cost-cutting practices that do not contribute to reclamation and manipulations that actually enhance the postmining land use.

Although most State regulations recognize alternate land uses, the red tape and resistance met by such applications discourage their submittal. Even in sparsely populated Montana and Wyoming, cropland, recreational areas, housing, and industrial uses should be considered as postmining options. For example, much native range today is being broken for small grains seeding--it would be better to preserve the undisturbed range and allow some mine sites to be converted to wheat or where appropriate to alfalfa production. Near metropolitan areas, parks and golf courses are realistic alternatives, as are industrial areas and housing developments. Alternate land use applications should be evaluated in terms of the surrounding land uses and within the restrictions imposed by the operating ranch unit which will absorb the land area after bond release.

The ramifications of alternate land use decisions are numerous and are often used as a reason for rejecting such land use proposals. Original topography may need to be sacrificed to provide space for efficient utilization of modern farm equipment. Premining surface drainage patterns as well as original topography may have to be altered to accommodate housing developments with aesthetically and physically pleasing surroundings. These are considered by some to be undesirable consequences of such actions, but other unquestionably beneficial effects may also accrue, such as increased livestock productivity because of greater accessibility to water and better forage. In any case, postmining land use decisions must insure the integrity of the agricultural base of the Great Plains: the livestock-wildlife and native range relationship. Our land ethic should not permit the abuse of this long-term asset of our country. Within this framework, however, flexibility should be allowed to permit the landowner to increase the long-term value of the mined land within his operating ranch unit. Rather than restricting our concept of land use to past activities and practices, we must strive to move forward with new, imaginative, and progressive land use and reclamation activities.

POSTMINING RECLAMATION ACTIVITIES

Some reclamation activities precede mining (e.g., topsoil stripping), but for convenience, all may be considered to take place after mineral removal. There are four basic components of reclamation: (1) spoil shaping and aquifer reestablishment, (2) surficial soil application, (3) revegetation, and (4) management. Each of these categories will be briefly reviewed and the pertinent guidelines evaluated.

Spoil Shaping and Aquifer Reestablishment

State and Federal strip mine reclamation rules specify that mined lands must be returned to their "approximate original contour." These same regulations place slope restrictions on reclaimed lands. The obvious intent of the law is to reduce erosion hazards and to permit easy movement of animals through and around reclaimed areas. The law accomplishes these purposes but at an often unnecessary expense. For example, large expanses of mixed grass-forest-shrub habitat are mined and revegetated as rolling grassland. The loss of wildlife habitat from these areas because of the loss of variable slopes has not been estimated.

One of the principal arguments against steep slopes is the threat of erosion posed by unconsolidated spoil materials. Any slope presents an erosion problem to some degree, depending upon slope length as well as soil texture and erodibility, among other factors. Stable, natural slopes tend to have concave surfaces. Using this configuration during spoil shaping instead of the convex or straight slopes found on most mined lands would resist erosion. Furthermore, intelligent retention of natural rock formations, bluffs, or highwalls would lend erosion-resistant variety to an otherwise uniform and monotonous postmining landscape.

Strip mining is terminated when the overburden-to-coal ratio becomes so great the cost of handling overburden exceeds the value of the mineral resource. On the relatively level coal seams of the Northern Great Plains, this may occur rather abruptly, for example, when the coal vein is overlain by a steep-sided hill or butte. The law requires that the final cut be backfilled at the approved slope to the level of the original land surface. An alternative in some cases would be not to backfill the final cut and retain the highwall as an extension of a pre-existing slope of relatively stable geologic material. Depending upon the slope materials and aspect, the slope face may support a pine forest, a deciduous shrub community, scattered clumps of bunch grasses, or be almost barren of plant life. In any case, the variation in landform and vegetation provided by the bluff and its extension would be of greater value to wildlife than the few acres of rolling grassland created by strict interpretation of the law.

Regulations adequately address recontouring for livestock grazing but they do not fulfill the needs of wildlife. Most game and nongame species profit from a variety of habitats, yet the mature reclaimed mine site will be composed of one habitat: rolling grassland. The habitat diversity provided by retention of a few judiciously selected highwalls would be an asset to the mined-land environment. Timbered or shrub-covered slopes provide food, escape cover, and protection for deer, small mammals, and birds, while more barren, grassy and shrub-studded slopes supply winter feed for these animals or at least potential nesting sites for birds of prey.

Present laws and guidelines closely regulate the topography of the postmining landscape and hence the drainage of the disturbed site. These regulations are so rigid, however, that they do not permit modification of the original surface-drainage pattern to improve the water-holding capacity of the site or reduce potential erosion problems. Water impoundments and drainage channel modifications might well be used to improve water availability for livestock and wildlife, increase landscape diversity, and reduce the threat of erosion.

The use of permanent manmade diversions to either impede or facilitate the downslope movement of water has long been practiced in Asia and Europe. The almost total exclusion of such structures from mined lands on the Plains prevents the impoundment of scarce surface water. Properly utilized depressions could increase on-site storage and infiltration of water, which are both beneficial in semiarid regions (Gardner and Woolhiser 1978). The control of runoff velocity by use of erosion-resistant channels to conduct water down steep grades past erosion-prone soils is required in Eastern coal fields but prohibited in the West. Very limited research would be needed to modify Eastern techniques and practices to Western precipitation regimes, soils, and vegetation. Impoundments and water channels could then be used in approved locations to control surface water flows over sensitive areas, thereby reducing the probability of erosion and increasing on-site water retention and availability.

Spoil shaping cannot be separated from aquifer reestablishment on mined lands. When overburden is stripped from one cut it is placed as fill into the preceding excavation. It is assumed that groundwater drainages disturbed by overburden stripping and coal removal will reestablish in the spoil material. Unfortunately, research is not available to show that aquifers of quality and quantity equal to those of the premining state will develop in Western mined areas. Since water is the limiting factor in biotic systems on the Great Plains, any activity that disrupts groundwater flow or storage patterns must be carried out with caution.

Potential mine-site aquifer characteristics may be acquired from geologic site descriptions and well sampling. However, aquifer interchange and groundwater influences on surface water phenomena are not as easy to describe. Problems occur when premining aquifer descriptions and our rudimentary hydrologic knowledge are used as a basis for predicting characteristics of the postmining hydrologic system. Changes in hydraulic conductivity of the new aquifer material will alter water flow through the mine area. Changes in mine area recharge or storage capacity will also alter the new aquifer. Downslope hydraulic gradients may differ from their premining condition. Furthermore, water quality appears to be adversely affected by contact with minerals in the new groundwater zone (Van Voast *et al*. 1978, Woessner *et al*. 1981). The ultimate effect of these changes on above-ground manifestations of aquifers (e.g., springs, seeps, stream flows, stock ponds) is poorly understood. Attempts to extrapolate from premining conditions to postmining aquifer characteristics are subjective and not based upon scientific fact.

Some research into the development of mined land aquifers is under way. Given the scope of projected coal mining on the Great Plains, this research is far from adequate. The investigations that have been completed indicate that subsurface hydrologic impacts of mining must be evaluated on a site-specific basis. The relative magnitude of the impact upon the system will determine the severity of the disruption and need for mitigating measures (Farmer and McWhorter 1980). Unfortunately, mitigating measures have not been investigated or defined.

The alluvial valley floor (AVF) protection clause of Federal and State reclamation laws is an example of an attempt to protect groundwater flow by regulatory authorities. When mining intercepts drainages that do not fulfill the requirements of an AVF, however, the destruction of some part of a groundwater system is initiated. Large mines or several mines in one area increase the magnitude of the impact. While the loss of one ephemeral groundwater source may not be observed downslope, cumulative losses will produce an adverse effect at some future date. Groundwater infiltration, storage, and flow must be rehabilitated as efficaciously as surface drainage patterns and vegetation. Research into this segment of Great Plains mined land reclamation has only begun.

Within the broad category of spoils reshaping and aquifer reestablishment, two problem areas are conspicuous: reconstruction of landforms as required by law with the resultant loss of wildlife habitat diversity and damage to aquifers. Both pose long-term questions, and there are no easy answers to either. To significantly change the laws and guidelines would threaten all that has been accomplished in the area of mine reclamation regulation in the past 10 years. Additional research may permit the development of reliable and accurate models to predict soil-water impacts from strip mining, but only site-specific evaluation of the long-term impact of changes in habitat on wildlife populations will clarify the former problem. If a mine is large enough to significantly affect big game and small animal populations, only judicious use of reclamation exemptions by regulatory authorities will alleviate the loss of wildlife habitat.

Surficial Soil Application

The advantages of topsoiling are numerous and the practice is required by State and Federal laws. Usually this surficial soil layer possesses the best physical characteristics for plant root development available at the site. It also contains a better supply of plant nutrients than overburden. Infiltration of water into and through as well as the water-holding capacity of this layer exceeds that of most other horizons. Although no field studies of direct-lift topsoiling have been done, soil microflora, insects, and plant propagules (e.g., seeds, rhizomes, roots, and entire plants) are alive in fresh topsoil and contribute to more rapid development of a mature soil-plant system (Beauchamp *et al*. 1975), Cundell 1977, Jensen and Hodder 1979). If the topsoil is stockpiled for any length of time, the number of these organisms decreases and soil nutrient cycles and biological processes in new minesoils are suppressed. Revegetation and soil reclamation are thus enhanced by direct application of surficial soil materials.

Regulatory agency interpretation of topsoiling requirements has led to a uniform distribution of this material on spoils. As with establishing a continuous rolling topography during spoil shaping, a uniform soil surface is created by applying the same depth of surface soil material on mined lands.

In an attempt to insure deep penetration of plant roots, most Western State reclamation guidelines also specify that a minimum depth of nontoxic root zone material must underlie the topsoil layer. The vast majority of rangeland plant roots are found in the top 12 inches of soil material (Sims *et al*. 1978), but many plants of the mid-grass prairie extend their roots below the 5-foot level and some plants of the true prairie reveal root penetration to 9 feet or more (Weaver 1958). These deeper roots insure water uptake during a drought. Thus, regulatory authorities are concerned with the material deposited in the root zone. At some mines this regulation necessitates special handling of overburden to insure the burial of toxic materials. Needless to say, this procedure is very expensive and resisted by mining companies. When segregation of nontoxic overburden occurs, the redistribution of a uniform subsurface material on overburden compounds the problems created by homogeneous topsoil and lack of topographic variation on the mined site.

A uniform surficial soil is created by the deposition of unchanging subsoil and topsoil layers on mined lands. Chemical properties, infiltration, and rooting depths are similar over large areas of previously highly variable rangeland, contributing to the development of homogeneous plant communities. Uniform topsoil and subsoil depths were not the condition of the landscape prior to mining. In the natural state, topsoil depth on the prairie varied from none on ridges to several feet in valley bottoms. The depth of desirable subsoil material was equally variable. The vegetation on such sites was as diverse as the soil layers. If the practices of variable topsoil and subsoil distribution were incorporated into reclamation programs, postmining vegetation could more closely approach the premining conditions of distinct plant communities across the landscape.

An example may clarify this point. Upper slope plant communities on better grazing lands of southeastern Montana are often characterized by the presence of the grass little bluestem (*Schizachyrium scoparium*) and associated forbs and shrubs. The A horizon on these sites is often restricted to a few centimeters or is entirely absent. Surface soils may consist of stony materials exposed by the downslope movement of finer soil particles. The toe slope often reveals topsoil depths of up to 2 feet or more. The vegetation reflects the change in surficial soil materials; deciduous shrubs and Kentucky bluegrass (*Poa pratensis*) or western wheatgrass (*Agropyron smithii*) are characteristic of toe slope sites. Attempts to rehabilitate these vegetative communities on evenly topsoiled spoil materials are wasted efforts. Unique planting programs or seeding strategies may succeed temporarily, but soil characteristics will exert selective pressures on plants that will direct succession toward a monotonous cover of a small group of plant species. To enhance landscape as well as community diversity, reclamation programs should more closely approximate premining site characteristics. Slopes and topsoil depth can be most economically adjusted to reflect these conditions.

Revegetation

The growth of vegetation on minesoils is still viewed by many as "reclamation." Because of its visibility, vegetation receives a disproportionate amount of publicity and attention from the general public, but it is only one of the many facets of mined land rehabilitation. Only 10 years ago, scientists were questioning whether mined areas of the Great Plains could even be revegetated. This question has now been laid to rest on the northern segment of this coal region, where research has shown that rangeland plant communities can be successfully established on minesoils. The seed companies have developed sources of native seed of many species previously unknown on their species lists. With the technology developed through research, and the plant species now available from private sources, the mine operator is able to propagate a variety of native plant species almost equivalent to the native prairie.

Although marked successes have been reported for the seeding of some grasses on mined lands (Depuit et al. 1980), various problems remain. Many of the so-called "cool season" grasses establish readily on minesoils when precipitation is adequate, but "warm season" grasses have not shown the same degree of ability to germinate and survive in this disturbed environment.

Many forbs and shrubs also fail to establish rapidly on minesoils. Presently, expensive tubelings have shown the most promise for successfully establishing rangeland shrubs and trees.

Questions as to the eventual success of revegetation of minesoils with native species can only be answered by long-term research. However, short-term research has been very encouraging and does indicate that the plant communities developing on recently mined lands can be managed to compare favorably with premining conditions or reference areas in livestock forage production.

The objective of most mine site revegetation programs is to rehabilitate grazing land. Early reclamation efforts showed that two or three species of introduced plants seeded on minesoils could produce as many or more pounds of forage than native range for at least a few years after seeding (compare results in DePuit et al. 1978 and Munshower et al. 1978). Immediate forage production is not the sole aim of reclamation, however; terms such as sustained grazing, plant diversity, animal nutritional needs, and seasonality are included in descriptions of desirable minesoil vegetation and are as important as pounds of forage. To rehabilitate mined lands with these concepts as guides, the reclamation scientist must depend primarily upon native plant species and, as pointed out in state regulations, preferably ecotypes of native species adapted to the climatic conditions and soils of the area.

Under any given set of climatic conditions some species of plants will express a competitive advantage. In general, grasses are more competitive than forbs or shrubs on the Northern Great Plains. In short-term studies, introduced grasses usually outcompete native species for available moisture and plant nutrients. In any given year, one group of plants in the revegation seed mixture will succeed to an extent that is detrimental to other seeded species.

Cool season grasses are well known for this aggressiveness in mixtures of native seeds. The success of a few species in a seed mix hinders the development of diverse plant communities on minesoils. One of the better methods devised to allow numerous species to develop in competition with cool season grasses is to refrain from seeding the more competitive species for at least one growing season. During this delay, less competitive species have an opportunity to germinate and develop a root system. Another approach requires evaluation of vegetation on the site one or more years after seeding. Species not present in quantities deemed adequate for the desired revegetation program may then be interseeded among existing plants. In both examples the mining company is penalized for its efforts by a corresponding setback in its bonded liability period. This interpretation of the law tends to restrict use of some of the latest reclamation techniques.

Other revegetation tools receive similar response. Practices such as shrub tubeling planting after the "last augmented seeding," irrigation beyond supplemental use immediately after seeding, or extensive tree transplanting on revegetated sites all add diversity and aesthetic quality to the landscape. To restrict these practices is to interfere with progressive reclamation programs that are striving to achieve the best possible vegetative development on minesoils.

The return of wildlife to mined areas in numbers and species equal to premining populations will be strongly influenced by rehabilitation of diverse habitats. Present mine reclamation regulations are guiding these areas toward a single homogeneous vegetative type. Uniform soils and slope throughout the mined area create successional influences that direct developing plant communities toward a common vegetative endpoint. Thus, a homogeneous plant community will develop despite reclamation efforts to create habitat diversity by using different seed mixtures on different portions of the landscape.

The variation in vegetative success on mined sites immediately after preliminary revegetation efforts creates a variety of habitat types and relatively fast invasion by numerous wildlife species. This rapid occupation of nitches is due to the habitat mosaic created by the progression of mining and reclamation. Plant community composition and landscape topography vary with the length of time since the last augmented seeding and spoil shaping. A temporary but dynamic complex of different successional stages extends across the mined land. First-year seedings are dominated by annual, weedy forbs, which provide secure nesting and resting areas for birds. If an initial cover crop was seeded, an abundant food source is added to the landscape.

In the second growing season after seeding, perennial grasses replace weedy forbs. Dead annuals still provide abundant cover and new perennial food sources are developing. This litter and new plant growth provide numerous nesting sites for ground- or low vegetation-nesting birds. Small mammals are protected from predators by the litter and new growth, and these species readily invade newly revegetated sites. Carnivores follow their food supply. As the reclaimed areas mature they will gradually reach an equilibrium with the management program at some stage along their successional gradient. One or two vegetative types may be distributed throughout the mined area because of the similarity of slope, topsoil depth, subsoil material, and water infiltration rate. The subsequent loss of habitat diversity will be reflected by a loss of wildlife species from these areas. Eventually, soil-forming processes such as sheet erosion of hilltops and fine material depostition at the slopes will create differences in the soils of the mined area and permit the development of diverse habitats. But this may take hundreds or thousands of years.

Reclamation laws emphasize the importance of wildlife on the Northern Great Plains. Guidelines even suggest measures to increase wildlife use of mined sites. The greatest deterrent to successful, long-term wildlife use of mined areas will be an absence of habitat diversity. The loss of this prerequisite for permanent colonization by birds, mammals, reptiles, and amphibians is encouraged by present interpretation of the requirements of reclamation laws.

Management

The previous topic overlaps this final component of the reclamation program--that is, how to manage reseeded lands for the 10 years until bond release may be requested. Because mining companies are now acquiring sufficient acres of mined lands under bond to become concerned about the disposition of this land until it qualifies for bond release, this area of reclamation science has recently generated much interest. Regulatory agencies themselves are in a quandary. Both parties are striving to find programs of minesoil management that will increase those floral characteristics that are the basis for revegetation performance standards.

Under the law and guidelines, 2 years of grazing are required prior to bond release to prove that the soil and vegetation will support livestock use. In effect, most mining companies are now utilizing livestock cropping programs or are planning to use such programs to harvest vegetatation on older minesoils. This may be as much as 5 or 6 years before the legal end of the bonding period. Grazing is the only management tool encouraged by most regulatory agencies. Other practices may be more desirable in specific situations, but are discouraged or not permitted--for example, the use of fire. Controlled burns can be very helpful to eradicate or control undesirable plant species on mine sites. On native range, fire is often used to control undesirable species and stimulate desirable plant growth. The use of fire on minesoils is not prohibited but restricted by provisions that do not permit its most advantageous use. Another tool of more limited use but no less desirable under appropriate conditions is mowing and baling for hay. This practice falls into the "not-permitted" category. The use of interseeding was mentioned in the "Revegetation" section; this often-valuable management tool, if implemented on minesoils after the last augmented seeding, may necessitate a restart of the 10-year bonding period.

Other practices developed in the future to stimulate and encourage plant community establishment and stability (e.g., mycorrhizaeinoculum) hopefully will not be met with blanket prohibitions from regulatory authorities. Such a reaction is unfortunate because all parties involved in reclamation of mine sites want to arrive at the same eventual goal, a rehabilitated range site. Such a site must meet the criteria of soil erosion control and plant cover, productivity, diversity, and seasonality stipulated in the laws and regulations. Any activity that helps achieve the goal of revegetation success should be encouraged, not restricted.

BOND RELEASE CRITERIA

Bond release criteria for the various segments of reclamation are as follows:

Land forms-- Must approximate original contour but no steep slopes are permitted.

Soil-- Topsoil must be stripped and reapplied, and subsoil must in some cases be stripped and redistributed; erosion must be comparable to reference area.

Water-- Surface drainage must be comparable to premining topography and erosion control; subsurface water must be comparable to premining conditions.

Animals-- Site must be capable of supporting premining numbers of cattle and wildlife.

Plants-- Permanent, diverse cover composed predominantly of native species must be present; productivity and cover must be comparable with premining inventory or reference area.

After spoil reshaping and topsoil replacement are completed, a portion of the reclamation bond may be released, but total bond release is based solely upon vegetative criteria and erosion control. No portion of the bond is held pending reestablishment of aquifers and the groundwater system despite bond release criteria that specify surface and subsurface water quality and quantity parameters.

Reclamation is not an activity involving a certain number of steps, as this paper and regulatory agency rules and regulations imply. It is a continuous process. Mined land rehabilitation requires the reconstruction of landforms, soils, aquifers, surface drainage patterns, and vegetation. The climax of the process resides in the vegetative covering produced on the minesoil.

Plant groupings evolve from simple aggregations of a few species to climax communities of many species (Fig. 2). During succession the community passes through a sequence of changes or seral stages. When revegetation is attempted on a mine site the reclamation specialist attempts to duplicate the seral state existing on the site prior to mining, or the seral stage of the reference area. All of the components of soil reconstruction and vegetation establishment discussed in this paper attempt to place the minesoil community at a point on the plant community life curve equivalent to or better than the premining vegetation state. The time necessary to accomplish this feat is determined in part by the seral stage of the premining plant community.

Postmining revegetation is an example of secondary plant succession. The solum has been reconstructed and seeding or planting augment the seed sources in topsoils. The classic stages of secondary plant succession are abbreviated but present during the first few years after seeding. The maturation of the plant community from the pioneer, annual weed stage to near-climax grassland will take many years and is not necessarily the most desirable reclamation program to adopt. Seral stages after early succession but before climax are more productive than the late seral stages and provide greater species diversity for grazing purposes. These mid-seral communities also reproduce themselves if maintained by grazing or other disturbance. Plant community successional stages posess a diversity of vegetation that increases in complexity with each seral state; therefore, later seral stages become more difficult to develop and require longer periods of time to duplicate (Fig. 2).

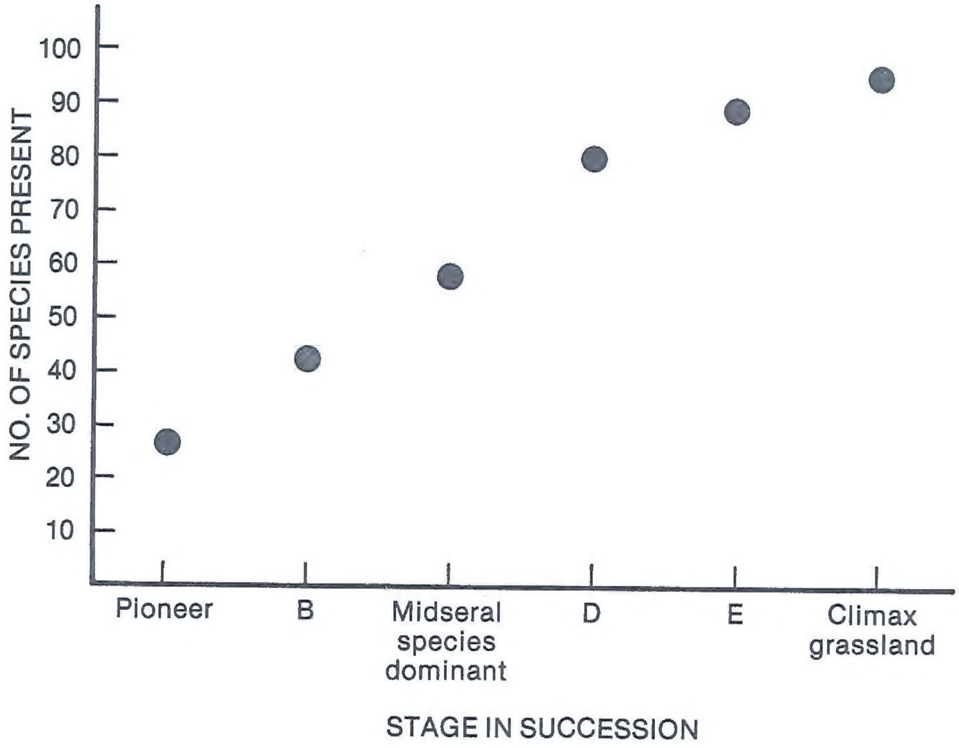

Figure 2. Number of species present at various successional stages (from: Smith 1940).

The minimum bonding period stipulated in the 1977 Federal Strip Mine Reclamation Act is 10 years. The use of a time period to measure reclamation success is counterproductive. Rangeland reclamation is not an activity necessarily accomplished in 1 year or 10 years. It is a dynamic process which takes varying lengths of time--it may occur in a few years at one site, 10 to 50 years at another, and possibly more than a human lifetime at still another site. Inclusion of a minimum time period in reclamation standards implies that reclamation should take exactly the time period indicated, which is often very misleading.

Evaluation of rangeland vegetation for bond release revolves around the terms "productivity," "cover," "diversity," and "native species." It is unfortunate that these words were selected, because they are static descriptors. They are based upon vegetation at one time point. If the mined ecosystem was a good range site (high production, cover, and diversity of native species), the criteria indicating successful reclamation may not be met for many years, probably several times the present minimum bonding period. If the mined area was a poor range site (much bare ground and few palatable species), the criteria could be met in less than 10 years.

The present use of the time period in bond release criteria is not appropriate. The performance of vegetation managed as grazing land and under the influence of the climatic regime of the area is the parameter to be estimated. Time is a factor in this evaluation, but only after the vegetative community has been established and is being managed for its designated postmining land use.

A danger inherent in present performance standards is that a vegetative state approaching reference area characteristics may be established on the minesoil, but because of the absence of the soil characteristics necessary to sustain the plant environment, a long-term regression may ensue. Numerous papers have documented the success of programs that produce highly productive and diverse stands of native vegetation on minesoils (Eddleman 1982, Coenenberg 1982) but none can attest to the ability of these stands to reproduce themselves successfully for 50 or more years.

This point requires some explanation. Premining plant communities are influenced by a number of factors, including other organisms, soil, land form, hydrologic properties (both surface and subsurface), management, and climate. Because of the interactions of all of these factors, this ecosystem developed a particular expression or assemblage of plant groupings. The expression of the premining vegetative system or of the reference area was defined at a particular point on a long successional scale (Fig. 2). Thus, vegetation was in equilibrium with all of the elements acting on the ecosystem at a particular point in time. Figure 2 illustrates this phenomenon with respect to the number of species present in various seral stages. Some parameters--organisms, soil, land form, hydrologic properties, etc.,--are disrupted by mining and cannot be restored in a manner that replicates the premining successional state. The plant communities established on the mine site, therefore, cannot perfectly duplicate the premining successional position. The plant community that will ultimately exist on the minesoil will be influenced by the same factors that determined the premining plant community composition, but since many of these factors have been altered, the postmining vegetation will also be changed.

If we isolate and examine only one factor--soil--its postmining divergence from premining conditions may illustrate this point. The soil resource is a complex of organisms and nonliving substances produced by plants and animals within a matrix of minerals weathered from parent materials. The surficial soil may be composed of a leached layer underlain by horizons containing deposits of finer soil particles as well as various chemical compounds and elements. Plant species have evolved different mechanisms to survive in various combinations of surficial and deeper soil materials. Pioneer species generally establish on bare mineral soils, while mid- or late-seral vegetation requires greater accumulations of soil organic matter, more complex and stable nutrient cycles, and other soil characteristics not present in bare mineral soils. The highly diverse soils of the premining site are stripped of their surficial soil and the remaining overburden is removed from the coal vein or other mineral deposit. A new soil is constructed after mineral removal. Reconstruction consists of recontouring the spoils, depositing several feet of nontoxic overburden material on the redistributed overburden, and covering the area with a layer of surficial soil. This topsoil, depending upon its source, may contain "A" horizon materials only, a mixture of "A" and "B," or of "A," "B," and "C" horizons. In any case, even when stripped and deposited in a single lift, the various properties of this surficial layer are disrupted and altered. The unique properties of different subsoils as well as topsoils are homogenized. The end product of the soil rebuilding process is a soil vastly superior to bare spoils but much inferior to the undisturbed soil system supporting good range sites.

As pointed out earlier, soils evolve slowly on mined areas (Schafer et al. 1979) and vegetation is intimately related to the soil in which it is growing. The two must evolve together. It is unlikely, therefore, that permanent vegetation complexes comparable to premining plant communities can be established within the time period specified in reclamation laws unless they are artificially maintained.

Mid- or late-seral stage plant species are emphasized by reclamation rules and guidelines. These are predominantly composed of perennial grasses and forbs, which require complex nutrient cycles and mineral regimes. These relatively steady-state processes in turn require a variety of soil macro- and microflora and fauna. Bacteria, fungi, mycorrhizal associations, algae, invertebrates, etc. must all function in the appropriate sequence and in conjunction with the root zone and physical environment to perpetuate a soil system adequate to the demands of mid- to late-successional stage plant species. The presence and functioning of these soil-system components would indicate that the minesoil is progressing toward a state that will support plant successional stages described as desirable on mined lands.

Reclamation performance standards could be modified to include such parameters, which would more accurately evaluate the long-term success of revegetation. One example would be a system based on the attainment of the functional capacity of the defined postmining land use and soil succession toward a more mature minesoil. Data collected under present guidelines could be used to evaluate revegetation performance, but other criteria would need to be included to evaluate soil maturation. If soil characteristics were included in the bond release criteria, sequential soil analyses could substantiate progression of the minesoil toward those characteristics indicative of a more mature native range soil. If vegetation and soils were maturing and the functional capacity of the range was being maintained (i.e., supports grazing) the bond could safely be released. Such a program may require 10 to 20 years on some sites, but this long bonding period would be balanced by faster bond release on sites that were poor grazing lands prior to mining.

Soil studies would assure that plant communities were not being artificially and temporarily maintained at some advanced seral stage. Soil evolution is much slower than plant succession, but soil development must coincide with plant community seral stages. The rate of soil maturation may be accelerated by man's manipulation of the ecosystem, but this is, in effect, what we are presently attempting to do on mined sites. We are forcing plant communities into advanced successional stages but we are not cognizant of the need for comparable maturity in minesoils to perpetuate these man-created plant seral stages.

SUMMARY

Present strip mine reclamation rules and guidelines are an adequate if not commendable first attempt. We now have the benefit of 10 years or more of rather intensive mined land reclamation research. It is time to evaluate the regulations, retain the best of them, but utilize the 10 years of research to improve weak points. Problems most mine site reclamation supervisors and reclamation scientists never thought existed 10 years ago have developed in the interpretation and enforcement of strip mine reclamation laws. Imaginative solutions to many of these problems are available. Although some Great Plains rangeland should not be mined, most rangelands can be mined and in some cases revegetated to better than premining conditions.

Despite problems and shortcomings of the laws and rehabilitation programs, vast improvements have occurred in reclamation as a result of environmentalist-rancher-farmer agitation, regulatory agency action, and mining company cooperation. Great Plains strip-mine reclamation is well beyond its infancy. If other mineral extraction industries follow the example set by the coal industry, the environmental amenities we assume as part of our Western North American lifestyle may be maintained.

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REGULATION OF COAL MINE RECLAMATION IN MONTANA

by

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INTRODUCTION

This paper discusses the development of Montana's coal mine reclamation regulatory program, the current program, and some of the inherent problems in administering that program.

EARLY STATE LEGISLATIVE REQUIREMENTS

The 1967 Montana Legislature passed Montana's first law designed to regulate coal surface mining. The act provided for "voluntary" contracts to be entered into, by, and between the Montana Bureau of Mines and Geology and the particular mining company (Montana Coal Task Force 1973, Montana State Legislature 1967). These reclamation contracts allowed the company to apply half of the reclamation costs incurred as a tax credit toward Montana's coal mine licenses tax. The 1967 act included no reclamation performance standards but instead left such standards to be negotiated between the company and the Bureau of Mines and Geology. The act also did not require a mining company to submit a reclamation performance bond. These early reclamation contracts were administered by the Montana Department of Natural Resources and Conservation in accordance with an agreement they had with the Montana Bureau of Mines and Geology.

In 1969, the legislature broadened the Bureau of Mines and Geology's regulatory authority by making the 1967-style "voluntary" contract mandatory for coal mining companies (Montana Coal Task Force 1973, Montana State Legislature 1969). The 1969 law included grazing, the submission of performance bonds, penalty provisions, and annual reporting requirements.

In 1971 the Montana legislature passed the Montana Open Cut or Strip Mined Land Reclamation Act (Montana State Legislature 1971b). This legislation, which repealed the 1967 and 1969 acts, regulated surface mining operations for coal, sand, gravel, clay, uranium, bentonite, and phosphate. The "Open Cut Act" was administered by the Department of State Lands and made it mandatory that operations removing over ten thousand yards of product or overburden be covered by a "model" reclamation contract (Montana Coal Task Force 1973). The contract required that a detailed reclamation plan be submitted to and approved by the Department of State Lands before mining could commence. The acres to be disturbed in any given contract year had to be bonded in an amount sufficient to cover the cost of all reclamation commitments made. This act also provided for substantial penalties.

THE MONTANA STRIP AND UNDERGROUND MINE RECLAMATION ACT

In 1973, the basis for Montana's existing coal mine reclamation legislation was passed amidst tremendous public concern as to whether acceptable coal mine reclamation was possible in the Northern Great Plains. This legislation, entitled the "Montana Strip and Underground Mine Reclamation Act," is administered by Montana Department of State Lands (Montana State Legislature 1973). Montana's strip mine act requires prompt restoration of surface topography, soils replacement, and the reestablishment of a permanent, diverse and predominantly native vegetative cover. It also requires the prevention of such offsite impacts as water quality deterioration and blasting damage, etc. Detailed environmental baseline studies are required to be submitted as part of a permit application. In late 1973 the Department of State Lands promulgated its first set of rules implementing Montana's strip mine act. Early technical experts used in implementing this act included wildlife biologists, range scientists, and geologists.

In 1977 the Federal government became involved with coal mine reclamation when Congress passed the Federal Surface Mining Control and Reclamation Act (U.S. Congress). This law established nationwide performance standards for both surface and underground coal mining. As with many Federal laws, the Federal strip mining act held out the carrot of allowing a State to administer the Federal program provided it would upgrade its reclamation requirements to the minimum Federal standards (Hayden 1982).

At the time of the Federal act's passage, Montana had one of the strongest state coal mine reclamation laws; through its Department of State Lands, it actively sought State coal program approval from the Department of the Interior. In 1979, to receive program approval, the State added to its strip mine law such requirements as greater protection of alluvial valley floors and other hydrologic systems, a small operator assistance program, and a citizen-initiated designation of lands unsuitable for a mining program (Hayden 1982, Montana State Legislature 1979). To gain permanent program approval, the department's rules implementing Montana's strip mine act were also greatly expanded to closely match those adopted by the Department of the Interior's Office of Surface Mining (Montana Department of State Lands 1980b). Concurrent with such changes, the department's coal staff grew from 6 to 13 members to include additional technical expertise in such areas as plant ecology, mine engineering, hydrology, soil science, and range management. Also, in accordance with a separate portion of the Federal Surface Mining Act, the department began administering a federally funded program for reclaiming abandoned coal and hard rock mines in Montana.

Coal mine applications in Montana must include a plan for the mining operation and for the reclamation of all land and water affected by the mine. Before such plans can be developed, however, detailed premining baseline information must be collected by the company including studies of overburden, hydrology, soils, vegetation, wildlife, land use, and cultural resources. Such data is used by the company and the regulatory agency to develop a reclamation plan that can comply with all of the various performance standards set down in reclamation law and rules. This is a dynamic process between the coal industry and the department and is one that can take two years or more to complete.

The grading of coal mine spoils must be kept current with the mining operation and no more than two spoil ridges may be left behind the active pit before regrading commences. Interior mine slopes cannot be steeper than a grade of 5:1, and highwall slopes must be reduced to a grade no steeper than 3:1.

In reestablishing the approximate original contours at mined areas, care must be taken to ensure that reestablished stream channels are geomorphically stable.

Surface waters that originate within permitted areas must be routed through a settling pond before being discharged. In addition, mine water discharges must also be permitted by the State's Water Quality Bureau pursuant to the Montana pollution discharge elimination requirement (Montana State Legislature 1975). No sediment or other mine debris is allowed to leave a permit area.

The Montana Strip and Underground Mine Reclamation Act requires that a suitable, permanent, and diverse vegetation matrix be established on strip mined areas. The primary revegetation performance standard is to restore the surface to a rangeland use and as such the legislature required that three basic criteria be met before bond can be released (Montana State Legislature 1973).

1. Feeding and withstanding grazing pressure from a quantity and mixture of wildlife and livestock at least comparable to that which the land could have sustained prior to the operation;

2. Strip mined vegetation must also be capable of regenerating under the natural conditions at this site, including drought, heavy snowfalls, and strong winds; and lastly,

3. Strip mined vegetation must be capable of preventing soil erosion to the extent achieved prior to the operation.

Where rangeland is the intended postmining use for a coal mine area, predominately native species are required to be planted. Where the company can demonstrate compliance with other performance standards, alternate revegetation is allowed for such purposes as a spring pasture or a wheat field. Alternate reclamation is also allowed to nonrevegetated uses such as industrial sites, etc.

The Montana Strip and Underground Mine Reclamation Act includes special protection for alluvial valley floors. The essential hyrdology functions (i.e., subirrigation) of these valleys must be preserved during the mining process and they cannot be mined at all in instances where a valley's value to the particular ranch in which it is located is significant.

Montana's strip mine law is particularly stringent with regard to the protection of water supplies. Before issuing any permit the department makes a series of written findings that must include a discussion of the cumulative hydrologic impacts of all anticipated mining in the area and a finding that material damage to both surface and ground waters in the area will not occur. Mining must be conducted to minimize disturbance to the hydrologic balance. Any landowner who believes that his water supplies have been damaged by mining can require the department to do a study of the problem. If the mining company is found to be at fault, the Department of State Lands must require the company to replace such supply with waters of like quality and quantity.

Coal mining is not allowed in Montana where reclamation, as required by the act, is unfeasible. It is also disallowed in areas that are special, exceptional, critical, or unique in nature. These criteria may be found in areas having one or more of the following qualities: biological productivity; ecological fragility and importance; or areas with scenic, historic, archaeologic, topographic, geologic, ethnologic, scientific, cultural, or recreational significance.

To ensure that the provisions of a permit are carried out, operators must file a reclamation bond with the department. Such bonds cannot be less than the amount required for the State to undertake the reclamation itself. In 1982 bonds held by the department for Montana's larger strip mines ranged from approximately $12,000 to $20,000 per acre.

Return of a bond is contingent on the mine operator's faithful performance in meeting the act's requirements. In no case can the total amount of a bond be released sooner than 10 years after the last year of site disturbance by seeding, fertilization, or irrigation. This does not include grazing, however, and in fact grazing is one of the tests used to determine whether bond release criteria can be met. Partial release of bonds is allowed upon the successful regrading of the spoils and retopsoiling.

An aspect of Montana's law that is very important is that of the avenues it provides for citizen participation in the department's decision-making process. All permit application material and departmental files are available for review by the public and the Montana strip mine act has numerous actions that can trigger a public notice or hearing, informal conference, or an on-site inspection by the aggrieved citizen. Probably most unique in this regard is a provision in the act whereby a citizen may petition to have an area designated as unsuitable for coal mining. Such petitions can lead to an intensive one-year evaluation of the allegations by departmental staff prior to making a decision on whether or not to designate the area as unsuitable.

PROGRAM STAFFING

The Reclamation Division of the Department of State Lands has the responsibility for overseeing coal mining and prospecting and also uranium mining and prospecting. The department does not hire separate technical and mine inspection personnel to undertake such duties. Instead, it is departmental policy to have each reclamation division member do both to ensure that mining and reclamation problems are looked at from a variety of perspectives. One week a hydrologist or engineer may be on a mine site and two weeks later it might be a wildlife biologist or range specialist. Continuous, on-site familiarity allows the staff to stay current with the ever-changing situation on the ground and provides an opportunity for each staff member to work directly with his or her company counterpart on field-oriented problems.

Considerable effort is expended by the department in hiring well-qualified individuals; it has a staff that is bright, energetic, and most importantly, committed to good mined-land reclamation. But there are problems.

Staff turnover in the Reclamation Division in 1978, 1979, and 1980 averaged about 18 percent per year and this definitely hurt the speed with which the department reviewed permits and resolved important technical issues.

Staff size is another problem area. The Reclamation Division's Coal Bureau currently has a staff of 13 to oversee all coal mining and prospecting in the State. In contrast, such major Montana coal producers as the Western Energy Company or Kiewit Mining and Engineering have as large or larger a technical staff to oversee as few as two mines. Most technical issues are settled between a company's technical expert (such as a soil scientist) and the department's expert. Such meetings can take a day or more of head-to-head debate and require considerable understanding on both sides in order for progress to be made. Whenever a new staff member comes on board, it usually takes six months or more before he or she is familiar enough with Montana's coal mines and their problems to have the confidence to make timely, but careful evaluations. The department does not have a large enough staff to provide much technical backup by older, more experienced members. Each new employee quite literally goes through an ordeal by fire. There is no such thing as a formal six-month training program.

The law that everything will take longer than planned is quite applicable to the coal mine permit review process, whether it be a cumulative impact evaluation, preparing an environmental impact statement (EIS), or refining a postmining contour map. Despite advance planning by both the department and the coal industry, emergencies are too often the rule rather than the exception. Protracted technical debates between company and regulatory experts are fairly common and this is set against the political background that Montana's people in general appear to want coal mining but want it tightly regulated. Pressure on the staff never seems to let up and it becomes a challenge to correctly pick those problem areas that deserve special attention from those that are routine and hence deserve a "once-over-lightly" approach.

The key to keeping top technical people in a mined-land regulatory program is to provide dynamic challenges and give the staff adequate time to work on them. Nobody in the reclamation business should be satisfied with mediocrity.

THE SPEED OF REGULATORY REVIEW

Permit review time frames is a subject that causes problems for both the regulatory agency and the coal company--for the company because they have contract commitments to meet and employees to keep busy--for the regulatory staff because to be continually working with a large backlog of unfinished tasks is unpleasant.

It takes an average of about two years for the Department of State Lands to make a permit decision on a new coal mine or on a major amendment to an existing operation. Montana's strip mine act and rules result in a tremendous amount of information being submitted to the departmemt. Typically the department will send a company two or three deficiency letters during the course of a permit review. Each letter is responded to by the company in the form of either mine plan changes or additional information. Essentially, the department and the companies go through a winnowing process until all requirements of the act rules have been satisfied in the form of written descriptions, maps, bonds, and other information.

But this process shouldn't take two years to complete! Once each staff member becomes familiar with the application and has visited the mine site, the actual time he or she spends on correcting deficiencies doesn't in reality usually exceed three or four weeks. But these three or four weeks never occur in one condensed block. Interruptions and delays too often occur, most of which are beyond the department's control. A typical review scenario might look something like this:

1. Because of the existing backlog of work, 60-90 days elapse before a permit application is opened for the first time; up to 240 days elapse before the department's first letter outlining deficiencies in the permit application is sent. This "deficiency" letter shows where an application is incomplete, inadequate, or incorrect.

2. After receiving the department's first deficiency letter, six months or more is often needed for the coal company to collect additional information and to respond to other issues raised by the department. The department's staff must to some degree refamiliarize themselves with the application when this new information is submitted.

3. The coal company's deficiency letter response often leads to additional deficiency letters and company responses, on-the-ground meetings, winnowing of the issues, and compromising.

4. Time is added to the permit review process to accommodate public interaction with the department. Citizen questions and complaints with regard to a particular mine are common.

5. Before a permit decision can be reached, the department must prepare written findings of technical compliance with the Montana strip mine act and the department's rules implementing this act (U.S Congress, Montana Department of State Lands 1980b). When Federal lands are included in a proposed mine, the written findings must contain letters of concurrence from the U.S. Office of Surface Mining, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and other Federal agencies.

6. Pursuant to the Montana Environmental Policy Act and the department's rules implementing the act, many coal mine permit applications require preparing an EIS (Montana State Legislature 1971a, Montana Department of State Lands 1980a). Impact statement preparation is integrated into the mine plan review

process to enhance efficient use of the departmental staff. Despite such integration, however, it is very difficult to prevent additional delays. The impact statement process requires in most instances the publication of both a draft and final document and includes extensive opportunities for public interaction.

7. In addition to the details of the permitting scenario listed above, there are other reasons for delays. Oftentimes, for example, permit review at one mine must cease while an emergency-permitting situation is handled at another. Also, coal companies will sometimes decide to amend an application that is close to being approved, thus setting time frames back. Perhaps, most frustrating of all is the situation where a key department staff member leaves in the middle of the review of a detailed and controversial permit application.

Chris Cull, the manager of permitting for the Western Energy Mine at Colstrip, believes that too much emphasis is placed on the bureaucratic process of mine permitting rather than managing the end result--that of ensuring compliance with high quality reclamation standards (Cull 1981). Unfortunately, to a large degree he is correct. With all of the requirements for written findings, EIS's, intergovernmental review coordination, and public hearings, etc., the Department of State Land's technical staff often becomes so bogged down with paper details that they can't spend enough time identifying problems occurring on the ground at the minesites or resolving technical issues.

It is a challenge to sort out what is most important to a regulatory program and then to do this first. Such prioritization may not necessarily be the same as what the Office of Surface Mining, a particular coal company, or public interest groups, think is most important. But it must be done if a coal mine regulatory program is to be effective.

REGULATORY FLEXIBILITY

Government regulatory staffs involved with coal mine reclamation must be innovative and realize that no State or Federal agency or coal company knows the only right way to solve a particular problem. No agency's rules, when strictly followed, can best describe how to solve every reclamation problem it faces. A flexible but firm regulatory posture is an important aspect of a successful program.

A key to regulatory flexibility is having an experienced staff. Over time, each professional becomes more confident in his ability to identify and then reach a solution to the problems with a particular permit application. Thus, they are able to make quicker, more realistic decisions. An experienced staff is also of greater assistance to the coal industry, especially the newer companies.

The original strip mine rules adopted by th Department of State Lands in 1973 included in several areas the phrase "or as otherwise may be approved by the department." This was important because it provided the department with a tool to approve a reclamation design that otherwise might not be allowed by the rules, but which the department felt was just as environmentally sound. The rule revision process the department went through in order to get Montana's state coal program approved by the Department of the Interior removed many of these phrases.

An example of the need for flexibility is in sediment pond sizing. If the department determines that a reduction of the size of a sediment pond below that required in the rules would reduce the area disturbed by mining while still preventing off-site sediment deposition, it should be allowed to approve such a design. The Department of State Lands often is presented with such "trade-off situations" and again staff confidence and hence understanding of the issue is key to flexibility.

Another key to succesful permit review is remembering that technical debate and multiple application revisions should be encouraged but, before a permit decision is made, the company's mining and reclamation plan must be corrected so that it is acceptable to the department and is consistent with the intent of the strip mine law. What is finally included in a company's application, when it is approved, becomes legally binding. If the company does not follow this plan or does not receive an amendment to the plan before commencing with a change in the field, legal action by the department will follow.

An inflexible regulatory attitude can encourage the companies to submit simple, noncontroversial mine plans written to minimally comply with the letters of the law and rules. This some believe will ease the decision-making process and hence help ensure quick, noncontroversial decision making. Such mine plans may not, for example, always be the most geomorphically stable or represent optimal wildlife habitat restoration for the area. Company innovation must not be stifled by the details of the permitting process.

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HISTORIC DEVELOPMENT OF RECLAMATION STANDARDS IN COLORADO

by

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INTRODUCTION

Since the first gold rush in 1858, many forces have shaped mineral development in Colorado. The highly diverse features of topography, geology, and climatology have combined with the market features of price fluctuation, union pressures, wartime economics, mining technology, price controls, and large corporations to be the force of mining. Just as these features have acted upon one another in shaping mineral development, so too have they acted upon each other in the development of reclamation standards in Colorado.

This study attempts to focus on the cause and effect relationship of forces that have affected the development of reclamation standards in Colorado. The study begins with a brief discussion of Colorado's environment, followed by a synopsis of a century of mining and a discussion of some of the resultant impacts on the environment. The study then turns toward an examination of several legislative attempts to set reclamation standards for mining.

COLORADO'S DIVERSE ENVIRONMENTAL CHARACTER

The Colorado landscape is characterized by diversity of geologic, topographic, and climatologic features. Colorado lies astride the Continental Divide, which physically separates the State into halves. Physiographically, the eastern half lies in the Great Plains Province, an area of rolling hills and plains formed from the deposition of materials eroded eastward from the mountains. The western half lies in the Southern Rocky Mountain Province, characterized by a mixture of high mountains, high mesas and plateaus, narrow to broad valleys, and large upland parks. Elevation ranges from 5,477 feet above sea level at the eastern border to 14,431 feet at the peak of Mount Elbert.

The climate is semiarid with an average annual rainfall of 16.5 inches per year. Precipitation ranges from 37.4 inches per year at Savage Basin in San Miguel County to 6.83 inches in Conejos County. Higher elevations can receive as much as 400 inches of snow. Temperature variations are extreme, depending upon elevation and geographic location. Summers are hot and dry in most parts of the State, excluding the mountains where moderately cool temperatures prevail. Winters are characterized by extreme cold in the mountains and moderate cold in the rest of the State. The growing season ranges from 17 to 191 days.

Vegetation ranges from sparse in areas above timberline and in arid portions of the State to heavy in the sheltered mountain valleys. The Western Slope is characterized by yucca, cactus, sage, juniper, and scrub oak, supplemented by cottonwood and aspen trees along streams and valleys. The predominant trees in the mountains are ponderosa pine, Engelmann spruce, Douglas fir, and aspen. The Great Plains are characterized by grasslands plus cottonwood trees along streams and rivers.

Geologically, Colorado is very prosperous; it has rich deposits of gold, silver, lead, zinc, copper, molybdenum, tungsten, fluorspar, vanadium, uranium, coal, oil shale, and several other minerals. So rich are the geologic deposits that only rarely have the highly diverse topography, extreme weather conditions, or other features precluded mining operations.

COLORADO'S MINING HISTORY

Mineral extraction has occurred in three distinct provinces: the Colorado Mineral Belt, the Uravan Mineral Belt, and the various sedimentary basins containing coal and oil shale. The Colorado Mineral Belt, which extends in mountainous swaths southwest from Boulder to the San Juan Mountains, is the result of mineral-laden intrusions into pervasive weaknesses in the Precambrian crust resulting in complex depositions of veins, displacement deposits, disseminated deposits and alluvial placers. Little hard-rock mining has occurred outside this region. The Uravan Mineral Belt extends in a semicircle from Polar Mesa, Utah, to Gateway, Uravan, and Slick Rock, Colorado. The predominant sandstones of the Uravan Mineral Belt yield radium, vanadium, and uranium.

The First Half-Century of Mineral Development

Mineral development began with the Gold Rush of 1858 when this precious metal was discovered in Cherry Creek near the present site of Denver. This discovery brought the first significant numbers of white men into the region. By the end of 1858, over 1,000 men worked the drainages of the South Platte River and had swarmed into the "foothills" of the Rocky Mountains. As a result of this influx, settlements such as Denver, Idaho Springs, and Black Hawk soon became established. The shallow lode ores and placers were soon mined out, however, causing a lull in the infant industry (Department of Natural Resources, 1981a).

The discovery of silver in 1864 near present-day Arapahoe Basin Ski Area in Summit County created the second initial boom for the mining industry. As smelting works were established, the demand for timber rose sharply. Entire hillsides were denuded to fuel the smelters, provide timbers for underground mine workings, heat surface buildings, and produce steam pressure to run the mine drills. As the supply of easily available timber was depleted, operators turned to coal to run the mine boilers and fuel the smelters. Transportation was a problem, however, since the smelters had been located in the rough mountainous terrain near the mines. Railroads, themselves dependent upon coal, seemed to be the solution and lines were hastily constructed into the foothills (Department of Natural Resources, 1981a).

New discoveries of silver-bearing lead carbonates in the late 1860s and early 1870s caused significant expansion of silver ore production. This discovery lead to the greatest rush in Colorado's mining history, as silver seekers pushed southwest along the Colorado Mineral Belt, flocking to the Arkansas River Valley. Prospectors and miners from the early districts were attracted, causing the early smelting centers to decline. The town of Leadville was founded and soon became the most advanced smelting center in the United States (Department of Natural Resources, 1981a).

This boom in the metal industry eventually gave rise to significant production increases in Colorado's coal fields. Coal development was also spurred by growth of the settlement of Denver. Here, wood served as an early fuel, but eventually became difficult to obtain. Construction of the first interstate rail connection from Cheyenne to Denver in 1870 solved the transportation problem and enabled expansion fo the Boulder-Weld Coal field adjacent to Denver. The railroad system quickly extended south along the foothills to the Trinidad-Walsenburg Field near the southern border of the State. The excellent coking quality of the coal in the Trinidad-Walsenburg Field was recognized, prompting the establishment of several mines and settlements. Much of the coal went by rail to Colorado Springs, then by wagon to Leadville. By 1879, the railhead was extended to Leadville through the Arkansas River Valley, causing the first surge of production from the Canon City Coal Field southwest of Colorado Springs (Department of Natural Resources, 1981a).

The prosperity of the Great Silver Rush continued into the early 1890s when a complex set of international events caused the price of silver to drop sharply. The resulting Silver Crash of 1893 precipitated a deeply depressed economy lasting until the turn of the century. The mining industry was significantly weakened, with the notable exception of gold and silver development near Pikes Peak and at Creede, near the southwest edge of the Colorado Mineral Belt (Department of Natural Resources, 1981a).

In less than three decades, mining had caused the settlement of a significant portion of central Colorado. Gold and silver production had pushed westward to the Continental Divide. The rail transportation system connecting the settlements, metal mines, and coal fields extended from border to border along the foothills of the Rocky Mountains and westward to the edge of the Divide. Coal supplied fuel for metal mining and smelting operations, for the steam locomotive, for the generation of electricity to operate electric cars, and for street light and domestic purposes (Allen 1960). By 1890, statewide coal production--primarily concentrated in southern Colorado--reached more than 3 million tons per year (Dawson and Murray 1978).

The Second Half-Century of Mineral Development

The early 20th Century saw a revival in the economy and the mining industry. This revival was not without change, however. No longer could an individual go forth with "pick and ass" to stake a claim. Technological advances and the inevitable exploitation of the nonrenewable resources saw the development of an increasingly mechanized and centralized industry. Low grade base metal recovery began to take the place of production from the rich veins and deposits of the past. Many of the dumps in the "old" silver districts were reworked as new extraction techniques were developed. The days of the bonanzas were over (Department of Natural Resources, 1981a).

With economic recovery of the metal industry, coal production, concentrated in southern Colorado, accelerated. Turn-of-the-century production was accented by centralization. One company--Colorado Fuel and Iron (CF&I)--produced more than half of the State's coal. CF&I's production was five times the production of its closest competitor, which in turn produced three times more than any other. As coal production expanded in the south, the industry was disrupted by several major coal and mine explosions. In 1910 alone, over 300 miners were killed. The resulting labor-management disputes caused a general decline in production in the Trinidad-Walsenburg Field, a decline which lingered until World War I (Department of Natural Resources, 1981a).

During this period of strife in Colorado's southern coal fields, other areas continued to develop. Production in the Boulder-Weld Field increased. Development was also spurred in northwestern Colorado with the extension of the railroads west of the Continental Divide in 1911. Statewide coal production peaked in 1918, during World War I, with a production of over 12 million tons per year. A steady decline followed, caused by a reduction of metal mining, introduction of the diesel locomotive, and substitution of oil, natural gas and hydroelectric power that would continue through 1960. Production would not again equal the 1918 peak until the late 1970s (Dawson and Murray, 1978).

Following World War I, the mining industry collapsed, with the notable exception of the production of molybdenum, an alloying element for strengthening and lightening steel. The Climax Molybdenum Mine began major production near the middle of the Mineral Belt in Lake County. This mine seems representative of the new era of mining very low-grade disseminated hard-rock ore bodies (Department of Natural Resources, 1981a).

World War II saw many developments in the industry. Several exploration projects were begun as a result of efforts by the U.S. Bureau of Mines to evaluate the base metal resources in the silver mining districts. Production of precious metals was all but snuffed out as the War Production Board ordered all gold mines closed in order to divert materials and labor toward the production of war-essential minerals. Emphasis was placed on production of base metals and on alloying elements such as tungsten and molybdenum. The demand for steel, thus coking coal, gave mines in the Trinidad-Walsenburg Field one last big push (Department of Natural Resources, 1981a).

Following World War II, the mining industry generally dwindled through the 1950s. This era did, however, see a resurgence of mining west of the Divide with the discovery of uranium. The discovery, initiated by the Atomic Energy Commission's exploration and development subsidies, programs, and guarantees, soon turned into a boom reminiscent of the great ore strikes in the 19th Century. This boom in the Uravan Mineral Belt continued into the 1960s when the subsidies were withdrawn. Today, the uranium industry is in a pronounced slump (Department of Natural Resources, 1981a).

While the uranium industry declined, coal mining began to grow steadily, from a production of 3 million tons per year in 1960 to over 12 million in the late 1970s (Dawson and Murray, 1978). The post-World War II era saw the age of the bulldozer and shovel. Underground coal production was enhanced by the invention of the continuous miner in Weld County. Yet no underground mine could match the production of the strip mines in northwestern Colorado. Today, a half-dozen large strip mines dominate production in the State, primarily supplying coal to electric plants. Metallurgical coal production from the Trinidad Walsenburg Field continues to be dominated by CF&I, while major underground mines also operate in the western portion of the State. Oil shale, Colorado's other solid hydrocarbon energy resource, seems destined to be heavily developed on the Western Slope in the future.

IMPACTS OF MINING

Mineral exploration and any subsequent mining and mine site processing affect the environment in many ways. Given the combination of natural diversity of Colorado's environment and a century of mineral development, it is not surprising that many impacts have resulted. Conspicuous among these is the degradation of surface and ground waters by drainage and seepage from mine workings, through waste dumps, and mill tailings. Of unknown consequence is the threat of radioactive contamination by windblown dust from uranium mill tailings and waste dumps. Other concerns relate to the difficulty of revegetating certain disturbed areas, damage to fish and wildlife habitat, surface subsidence, negative aesthetics, and dust.

During the summer of 1980, the Inactive Mine Program of the Colorado Mined Land Reclamation Division undertook a statewide inventory of the inactive mines. This inventory sought to identify inactive or abandoned sites and evaluate the extent of any environmental problems attributed to past mining. The compilation of these data shows a broad range of impacts, from scarcely perceptible to highly obtrusive. The nature of these impacts varies widely depending upon the mineral worked, the method of mining, and the characteristics of the mine site and its surroundings (Department of Natural Resources, 1981b).

Some of the impacts inventoried were:

> Shafts, inclines, adits, and open pits where inadequate fencing or sealing could be the scene of an accident. Old workings were generally found to have a high hazard potential since few, if any, safety measures were taken at the time of abandonment and natural vegetation may now camouflage potentially dangerous mine openings. Additionally, the edges of a vertical shaft are often composed of unconsolidated material which may give way beneath the weight of a visitor. Aside from the danger of collapse or a fall into a shaft, idle mines often have very poor ventilation. Poisonous or explosive gases may be present and oxygen levels dangerously low. Several potentially hazardous situations were found in close proximity to housing developments where children are known to play, or adjacent to areas frequented by the public for recreation.
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> Subsidence associated with underground mining where the removal of a mineral body inevitably leads to some stress readjustment and resulting ground movement. These impacts, which may affect some 6,300 acres in the State, range from the appearance of sink holes and surface tension cracks to the complete collapse of the earth's surface. Subsidence was found to be a particularly significant hazard along the "front range" area where coal was extracted by underground mines in

several areas adjacent to or directly beneath heavily developed areas.

Water draining from or through a mine site causing physical and chemical hazards. Physical hazards arise where the volume of water is enough to cause severe gullying, downstream deposition, or instability. Chemical hazards result from the gradual release of toxic substances, especially metal ions and chemical reagents, into a water supply, directly impacting aquatic life and potentially impacting water used for public consumption. Surface water quality has been seriously impacted by past mining in several major drainages. Groundwater quality, although not studied in as great detail, has also undoubtedly been affected.

Along the "Front Range," over a dozen instances were found in which a mine or wastebank was burning. In several instances, young children have been severely burned and recreationists or wildlife have succumbed to noxious gases.

Although the detrimental impact of mining upon the land, air, and water resources may have been present since the first Gold Rush in 1858, it is only within the last half-century that problems have become acute. And it has only been within the last 10 to 15 years that public concern over the effects of mining became prominent enough to warrant legislative control measures designed to reduce the adverse impacts of mining.

ORIGINS OF REGIONAL AND NATIONAL STANDARDS

In reviewing the historic development of reclamation standards in Colorado, many parallels can be drawn between the development of standards in the West and on the national level. So striking are the similarities that it seems Colorado's reclamation standards may be largely a product of regional and national trends. Thus, it is instructive to briefly review some of the events which influenced the development of regional and national standards.

In 1967, the Federal government published an elaborately illustrated account of accumulated damage caused by past mining activities (U.S. Department of the Interior 1967). The statistics included 20,000 miles of unreclaimed highwalls in the Appalachians, the disturbance of 4,000 acres of land each week in the West, one hundredfold increases in stream pollution, and instances of catastrophic loss of life and property.

In the West, fears about the impact of greatly expanded coal production were aroused in the early 1970s by ambitious plans for electric power plants in the Southwest and on the Northern Great Plains. The plans precipitated detailed Federal and State studies of coal and water resources and resulted in the compilation of several lengthy environmental impact statements (National Research Council 1979). Concerns centered on conflicts of surface mining with traditional land use patterns such as agriculture, the difficulty of reclaiming mined lands in the harsh environment, and the impacts of the socioeconomic fabric of sparsely populated regions. The earliest State control of mine reclamation dates to 1967, in Montana. By 1975, all of the western States, except Arizona, had adopted legislation dealing with reclamation of mined lands (Imhoff et al. 1976).

A study by the National Academy of Sciences in 1974 on reclamation practices in the West questioned the effectiveness of State control. The National Academy study found, for example, that

> "Most state laws governing surface mining and rehabilitation in the West do not provide for adequate planning, monitoring, enforcement, and financing of rehabilitation. State agencies charged with enforcement are generally understaffed, which impairs implementation of the intent of the law (National Research Council 1974)."

Citizen lobbies echoed this concern and called for strong national legislation. Initially, legislation before Congress to address these issues was an all-minerals bill for hard-rock surface mining and for mining of bedded deposits. This inclusive approach proved impractical, resulting in legislation after 1973 confined to coal (National Research Council 1979). Two major bills dealing with coal were vetoed prior to passage of the Surface Mining Control and Reclamation Act of 1977.

PRE-LAW RECLAMATION STANDARDS IN COLORADO

In 1965, concern over the increasing acreage of unreclaimed lands manifested itself in the first statewide attempt to set forth standards for reclamation --the Memorandum of Understanding. This was a voluntary agreement between the operator and the State setting forth specific reclamation obligations on a case-by-case basis. However, since this method was on a voluntary basis, without funding for administration, the Memorandum of Understanding did little more than officially document the reclamation initiative of a few companies (Heifner 1979).

Reclamation under the Memorandum of Understanding was sporadic. Where it was practiced, it was primarily due to local requirements or simply recognition of the opportunity to return the land to a beneficial use. For the most part, however, mined lands were left in a state of disrepair and in a few areas presented serious environmental and safety problems (Heifner 1979).

1969 RECLAMATION LEGISLATION

Dissatisfaction with the Memorandum of Understanding and the increasing acreage of unreclaimed land led to legislation setting forth the initial statutory reclamation requirements (Heifner 1979).

On July 1, 1969, Colorado General Assembly enacted amendments to existing mining law and a separate statute, the Colorado Open Cut Land Reclamation Act, setting forth requirements for stabilization of mined lands as necessary to prevent landslides, floods, and erosion (Colorado Revised Statutes 1969). The Comparative Statutory Summary (Table 1) delineates specific provisions of this legislation.

Although a first step, these standards represented little more than enactment of the Memorandum of Understanding into law. Several fundamental problems existed, the most important being the lack of any funding for administration. Consequently, reclamation under this legislation was not distinguishable from that performed prior to 1969. Little, if any, topsoil was being salvaged and revegetation success was poor (Heifner 1979). As a result, concern continued to grow as the acreage of unreclaimed lands increased. This concern is perhaps reflected best in a study of the "state of the art" of mined land reclamation in Colorado, completed in 1972 by the Rocky Mountain Center on the Environment (ROMCOE). This report, which excluded coal, found:

> ...that in many cases of the state of Colorado mining claim location, exploration and early development processes are carried out with little or no regard for environmental, ecological or reclamation principles. The violation of these principles seems to be largely a matter of careless neglect, but sometimes incompetent engineering seems to play a role. It seems unlikely that cost is a significant factor...
>
> ...With two notable exceptions, the mines of this type...seemed to be operating without regard for reclamation and ecological considerations. Waste rock was dumped over the steep edge of the quarry and waste materials were simply assembled in large conical piles at the convenience of the dragline. In some cases, sterile bedrock extended for miles along the strikes of beds and vegetation was needlessly destroyed for the convenience (not the necessity) of the mining operation (Rocky Mountain Center on the Environment 1972).

In 1972, amendments to the Colorado Open Cut Land Reclamation Act included additional permit application requirements, creation of the Land Reclamation Board to administer reclamation requirements, and, perhaps most important, limited funds specifically designated for reclamation program administration (Colorado Revised Statutes 1973). The recognition that mined land reclamation was a difficult subject requiring specialized personnel resulted in hiring the State's first reclamation specialist in April 1973 (Heifner 1979).

1973 RECLAMATION LEGISLATION

Reclamation standards under the 1973 statutes were limited. For hard-rock mines, the only specific requirements were that operators stabilize and reclaim areas disturbed or affected by mining activities as necessary to prevent landslides, floods, or erosion (Colorado Revised Statutes 1973). For coal mines or gravel operations, the standards were more explicit. The Open Mining Land Reclamation Act of 1973 required a permit and bond, initiation of reclamation with minimum time frames, and annual reclamation reports. Minimum performance standards were set for backfilling and grading, protection of the hydrologic balance, disposal of toxic materials, and revegetation (Colorado Revised Statutes 1973).

For the most part, these standards did not ensure adequate reclamation. For example, the backfilling and grading performance standards were limited to striking spoil edges and peaks to widths not less than 15 feet before seeding. Reclamation in accordance with this standard did little toward returning the land to some beneficial use.

Although the groundwork of setting forth operator obligations, minimum performance, and enforcement provisions was laid, progress toward adequate reclamation of mined lands continued to be slow. Even with the addition of two reclamation specialists in 1974, a staff of three could not effectively handle an estimated 1,200 mines (Heifner 1979).

THE COLORADO MINED LAND RECLAMATION ACT OF 1976

In late 1975, the Department of Natural Resources initiated a push for a strong, comprehensive reclamation program. As part of this effort, the Mined Land Reclamation Division was created in early 1976 (Heifer 1979).

On July 1, 1976, strong reclamation legislation was realized with the enactment of the Colorado Mined Land Reclamation Act. This statute embodied the administrative lessons and reclamation concepts gained since 1969 into a comprehensive law applicable to the mining of all minerals, but it excluded water, geothermal energy, oil, and gas. It included specific provisions for large operations, small operations (less than 10 acres), public participation, enforcement, and bonding.

The Mined Land Reclamation Board was designated as the administering agency. The Board consists of a seven-member citizen body representing a diverse cross-section of interests which are, or could be, affected by mined land reclamation, including agriculture, environment, industry, and regulatory agencies (Colorado Revised Statutes 1976).

Under the specific provisions of this law, any operator proposing to engage in new mining operations must first obtain a permit from the Board. A permit application must contain a legal description of the affected land, a detailed description of the proposed mining operation, and a reclamation plan for the affected land which includes a timetable showing how and when the plan will be accomplished. Prior to issuing a permit, the Board must hold a public hearing and receive a bond or other surety from the applicant equal to the cost of reclamation. Additionally, each application must have the concurrent approval of the county in which the operations are proposed before the permit becomes effective. Once granted, the permit remains in effect for the life of the mine, provided the operator complies with conditions of the permit and with applicable statutes and regulations, including the annual submission of a reclamation plan and progress report (Imhoff *et al*. 1976).

Specific performance standards were set forth in an effort to ensure the return of land to some beneficial use (see Tabel 1). Backfilling and grading were required to create a topography consistent with the final reclaimed land use. Minimizing disturbance to the prevailing hydrologic balance and disposal of toxic-producing material were required. Where overburden is removed, topsoil must be salvaged, and revegetation, where necessary for the final land use, must be diverse, effective, long-lasting, and capable of self-regeneration. Use of native species was emphasized (Colorado Revised Statutes 1976).

COLORADO SURFACE COAL MINING RECLAMATION ACT OF 1979

On August 3, 1977, the Federal Surface Mining Control and Reclamation Act (SMCRA) was signed into law. Passage of SMCRA reflected national concern for large economic and social costs of past coal mining. Congress recognized the inadequacies of State laws and Federal requirements which did not force the coal industry to meet established environmental standards. Failure to enforce those standards in place in a number of States reflected inadequate funding and manpower. In the West, huge tracts of public lands and the economic and technologic changes favoring surface mining also seemed to magnify the concern for extensive damage caused by coal mining in the East. Colorado elected to administer this new program (U.S. Department of the Interior 1979).

State Program

On July 1, 1979, the Colorado Surface Coal Mining Reclamation Act, the State equivalent to SMCRA, became law. Passage of this Act reflected the State's determination to maintain control of the regulation of coal mining in the face of threatened Federal preemption. The need was perceived as particularly acute since SMCRA seemed to result largely from reaction to environmental impacts of mining in the Appalachian region (Barry and McCarthy 1979).

The Act provides a comprehensive scheme for regulation of surface coal mining and the surface effects of underground coal mining. Its purpose is to mitigate adverse environmental impacts of coal mining and to assure that land disturbed or otherwise affected by coal mining is reclaimed. Coal is the only mineral subject to the provisions of the Act. Reclamation with respect to all other mining operations is subject to the Mined Land Reclamation Act of 1976. Since the Act was in direct response to SMCRA, similarity between the two is unmistakable. However, many important differences exist. For example:

> The Colorado Act perpetuated the regulation of reclamation by a multi-interest board. The Mined Land Reclamation Board functions primarily in an appeals capacity while day-to-day affairs are conducted by the Mined Land Reclamation Division. This arrangement reflects the Legislature's conviction that a multi-interest citizen panel should be charged with the ultimate responsibility for the administration of coal mining, rather than a completely administrative agency.
>
> The Colorado Act assures preservation of the legal principles of Colorado water law. SMCRA, it seems, largely ignores the fundamental differences between eastern riparian water law and the doctrine of prior appropriation governing water allocation in the West.
>
> The Colorado Act concerns itself with the preservation of the small miner. While coal mining in most other western States is dominated by a relatively small number of large operators, Colorado has approximately 25 mining operations producing less than 100,000 tons of coal per year. The Act applies the same performance standards and procedures to all operations but provides significant latitude for

technical and administrative assistance to those operations extracting less than 100,000 tons per year. In those cases, the Act directs the Division to conduct a determination of probable hydrologic consequences from test borings or core samplings. In addition, the Division is required to provide "necessary technical and administrative assistance" in all aspects of the preparation of the permit.

The Colorado Act alters the relatively open-ended information requirements of SMCRA, to provide that additional information, not specifically covered by the Act, can only be required by the regulatory authority for "good cause shown."

The Colorado Act provides strict time frames for administering the permitting provisions. This is perhaps the most important difference from SMCRA, which requires only that a permit be acted upon "within a reasonable time." The Colorado Act requires that each of the detailed administrative steps be taken within prescribed time frames.

The Colorado Act largely duplicates the performance standards articulated in SMCRA, primarily because these standards are perceived as fundamental to any reclamation program and subject to strict adherence. These performance standards require:

Restoration of disturbed lands to a condition equal to or better than before mining.

Return of disturbed lands to the approximate original contour.

Stabilization and protection of all surface areas during and after mining.

Minimizing disturbances to the prevailing hydrologic balance.

Protection of alluvial valley floors.

In addition, the Colorado Act applies to "surface operations and surface impacts incident to an underground coal mine." Underground operations must comply with most of the detailed performance standards for surface mines even though special performance standards, such as preventing material damage by subsidence, are developed for some aspects of underground operations (Colorado Revised Statutes 1979).

Upon enactment of the Act, Colorado set out to complete the development of the State program. This process, initiated in July 1979, involved the compilation of a regulatory and administrative program to ensure that Colorado could carry out the intent and purposes of SMCRA. The final State program submission, submitted to the Office of Surface Mining on February 29, 1980, included: The Act; regulations implementing the Act and consistent with Federal regulations under SMCRA; the submission of an Attorney General's opinion comparing the State and Federal Acts and the State and Federal regulations; paragraph-by-paragraph explanation of significant differences; 16 narrative descriptions and related flow charts for all elements of the program; copies of supporting agreements between State agencies; statistical information concerning the coal industry in the State; and various documents concerning budget, personnel, and physical resources. On December 15, 1980, 18 months after initiation of program development, the Secretary of the Interior conditionally approved Colorado's State program (Barry 1979).

Cooperative Agreement

The next step is the Cooperative Agreement. SMCRA allows any State with an approved State program to enter into a Cooperative Agreement with the Secretary of the Interior to provide for State regulation of coal mining on Federal lands within the State. The Secretary must determine in writing that the State has the necessary personnel and funding to fully implement such a Cooperative Agreement in accordance with the provisions of SMCRA. It is important to note that the Cooperative Agreement only allows States to share in the regulatory responsibilities for Federal coal development with respect to the reclamation requirements. This is an important point, since certain parts of SMCRA, the Mineral Leasing Act of 1920, the National Environmental Policy Act, the Endangered Species Act, the National Historic Preservation Act, and other applicable legislation, prohibit the Secretary from delegating responsibility for the protection of the public interest during the development of coal resources on Federal lands.

On October 6, 1982, Colorado's permanent program Cooperative Agreement was finalized by publication in the Federal Register. The Cooperative Agreement provides that the laws, regulations, terms, and conditions of Colorado's State program be applicable to all Federal lands within the State. In effect, the Colorado program is substituted for Federal reclamation law and made enforceable by both the State and the United States. As stated in the proposed agreement, its purpose is to foster Federal and State cooperation in the regulation of coal mining on Federal lands, eliminate intergovernmental overlap and duplication, and provide uniform application of the State program on Federal lands in Colorado. Under the agreement, the Division serves as the "focal" agency.

The concept of a focal agency is extremely important for the coordination of the various Federal agencies involved (U.S. Department of the Interior 1981). Within the Department of the Interior alone, at least five agencies are directly involved: the Office of Surface Mining (OSM); the Bureau of Land Management (BLM); the U.S. Geological Survey (USGS); the National Park Service (NPS); and the U.S. Fish and Wildlife Service (USFWS). The number of agencies directly or indirectly involved often results in an exceedingly complex jurisdictional maze. The following discussion presents an overview of the primary responsibilities of those agencies most directly involved in coal management on Federal land during three phases: pre-leasing, pre-mining/post-leasing, and mining. For purposes of this discussion, responsibilities of the Mined Land Reclamation Division (MLRD), as outlined in the proposed Cooperative Agreement, have been noted.

TABLE 1. COMPARATIVE STATUTORY SUMMARY

Statute	Open Cut Land Reclamation Act[1]	Concerning Stabilization of Earthworks[1]	Open Mining Land Reclamation Act[2]	Concerning Earthwork Stabilization and Reclamation[2]	Mined Land Reclamation Act[3]	Surface Coal Mining Reclamation Act[4]
Date	1969	1969	1973	1973	1976	1979
Regulated Minerals	Coal/Surface	Coal/underground, rock and stone quarries, clay pits, sand and gravel pit excavation, and metals	Coal, sand, gravel, quarry aggregate, and limestone for construction purposes	Coal/underground rock and stone quarries, clay pits, sand and gravel pit excavation, and metals	All minerals except water, geothermal, oil and gas	Coal
Administering Agency	Department of Natural Resources	Colorado Bureau of Mines	Land Reclamation Board	Colorado Bureau of Mines	Mined Land Reclamation Board	Mined Land Reclamation Board/ Mined Land Reclamation Division
Permit Required	*		*		*	*
Term	1 year		5 year		Life of mine	5 year
Reclamation Definition			...employment during and after an open mining operation of procedures reasonably designed to minimize as much as practicable the disturbance from the open mining operation and to provide for rehabilitation of any surface resources adversely affected ...through the rehabilitation of plant cover, soil stability, water resources and other measures appropriate to the subsequent beneficial use of such mined and reclaimed lands.		...employment during and after a mining operation of procedures reasonably designed to minimize as much as practicable the disturbance from the mining operation and to provide for rehabilitation of any affected land through the rehabilitation of plant cover, soil stability, water resources and other measures appropriate to the subsequent beneficial use of such mined and reclaimed lands.	...any activity or procedure required to achieve compliance with a reclamation plan...including any necessary work required for compliance with the Act...[5]
Surety Required	*		*	*	*	*
Amount	Determined by Department but not greater than $100/acre		Determined by Board		Determined by Board with consideration for reclamation cost	Sufficient to assure reclamation completion
Statute	Open Cut Land Reclamation Act	Concerning Stabilization of Earthworks	Open Mining Land Reclamation Act	Concerning Earthwork Stabilization and Reclamation	Mined Land Reclamation Act	Surface Coal Mining Reclamation Act

TABLE 1. (Cont.)

Hydrologic Balance	Divert mine drainage to control siltation, erosion or other damage to streams		Divert mine drainage to control siltation, erosion or other damage to streams		Minimize disturbance to prevailing hydrologic balance of affected land and of surrounding area and to quantity and quality of surface and ground water, both during and after mining	Minimize disturbance to prevailing hydrologic balance at mine site and associated off-site areas and to quantity and quality of surface and ground water, both during and after mining
Backfilling and Grading	Strike spoil ridges to a minimum top width of 15 feet	Stablize as necessary to prevent landslides, floods and erosion	Strike spoil ridges to a minimum top width of 15 feet	Stabilize and reclaim as necessary to prevent land slides, floods and erosion	Grade to create final topography consistent with final land use	Backfill, compact where necessary to provide stability or prevent leaching of toxic materials and grade to restore approximate original contour of land
Revegetation	Revegetate as necessary to achieve final land use		Revegetate as necessary to achieve final land use		Revegetate as necessary to achieve final land use, establish diverse, effective and long-lasting vegetative cover, capable of self-regeneration and at least equal in extent of cover to natural vegetation of surrounding area	Establish on all regraded lands, and all other lands affected, a diverse, effective and permanent vegetative cover of same seasonal variety native to area and capable of self-regeneration and plant succession at least equal in extent of cover to natural vegetation of area
Subsidence						Adopt measures consistent with known technology to prevent subsidence causing material damage to extent technologicly and economically feasible, maximize mine stability and maintain value and reasonably foreseeable use of such surface lands

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[1] CRS 1963, as amended, Sections 92-3-1 *et seq*, 1969 supp.
[2] CRS 1973, as amended, Sections 92-3-1 *et seq*.
[3] CRS 1973, as amended, Sections 34-32-101 *et seq*, 1976 supp.
[4] CRS 1973, as amended, Sections 34-33-101 *et seq*, 1979 supp.
[5] 2 CCR 407-2, Rule 1.04.

Pre-leasing:

USGS evaluates the coal resources;

BLM coordinates Federal lands review, prepares regional environmental impact statements (EIS) or site-specific pre-lease EISs concerning lease tract selection, prepares lease, represents Secretary in dealing with lease applicants, and must obtain surface owner consent;

OSM serves as consultation agency during Federal land review and processes unsuitability petitions on Federal lands; and

MLRD serves as consultation agency during Federal land review and during processing of unsuitability petition on Federal lands.

Post-leasing/Pre-mining:

USGS regulates post-mining exploration activities;

BLM coordinates use permits and pre-mining non-lease activities;

MLRD assumes primary responsibility for analysis and review of permit applications and revisions, serves as primary point of contact with applicant, assists OSM in preparation of site-specific EIS or environmental assessment (EA), approves or denies permit applications and revisions, and determines and receives reclamation performance bonds; and

OSM coordinates the review of applicable portions of permit applications with other Federal agencies, prepares site-specific EIS or EA, and conducts oversight authority over MLRD.

During mining:

MLRD assumes primary environmental enforcement function, serves as primary point of contact with operators, and assumes primary reclamation abandonment authority including release of reclamation performance bond;

OSM conducts oversight authority over MLRD and coordinates conduct of abandonment authority by other Federal agencies; and

BLM regulates non-mining functions outside the permit area and conducts release of lease bond.

FUTURE DIRECTION OF RECLAMATION STANDARDS IN COLORADO

Presently, Colorado utilizes two separate sets of reclamation standards--the Mined Land Reclamation Act for hard-rock mining and the Surface Coal Mining Reclamation Act for coal. As can be seen from the Table 1, many similarities exist between these standards. Both require the basic permit, surety, and adherence to performance standards. Differences arise primarily with regard to specificity of these standards. The Mined Land Reclamation Act necessarily applies a more general set of standards because of the varied character of applicable mining operations. Conversely, the Surface Coal Mining Reclamation Act applies a more specific set of standards applicable only to coal mining.

Each set of standards reflects the highly diverse environmental character of the State, a century of intense mineral development and the resultant environmental impact, regional and national concern for reclamation, and more than a decade of reclamation regulation. The reclamation standards contained in the Mined Land Reclamation Act and the Surface Coal Mining Reclamation Act represent an evolution. The product of this evolution represents the same intent--good reclamation in Colorado.

The future direction of reclamation standards will be a continuation of this evolution. Forces certain to shape it are the study results of the Committee on Surface Mining and Reclamation (COSMAR), the effectiveness of the reclamation standards, and State and Federal reclamation goals.

Section 709 of SMCRA, the surviving remnant of the original all-minerals bill, required an analysis of the applicability of SMCRA to non-coal minerals. The findings, completed in 1979 by the Committee on Surface Mining and Reclamation (National Research Council 1979), generally concluded that:

> The degree to which the requirements of SMCRA can be met by existing or developing technology of non-coal surface mining ranges from readily achievable to impractical depending upon site and mineral-specific circumstances.
>
> Some requirements of SMCRA cannot be met because of technologic or economic limitations.
>
> Sufficient alternative regulatory mechanisms and institutional approaches exist that could ensure achievement of the most beneficial post-mining land use for areas affected by non-coal surface mining operations.

The results of the COSMAR study enhance the continuation of regulation of hard-rock mining by State and local reclamation standards primarily under existing provisions of the Mined Land Reclamation Act. Current economic and political forces seem to enforce this direction. For the near future, little change can be expected in this area other than enhancement of the acceptance of State reclamation standards on Federal lands.

Regarding reclamation standards for coal, the process may be more dynamic. Currently, the Office of Surface Mining and the Federal regulatory program developed in 1978 are undergoing significant scrutiny and alteration. This reevaluation is also occurring within the other agencies of the Department of the Interior which have some role in the development of Federal coal. The results of the Federal reevaluation point toward strong State involvement in the regulation of mining on Federal lands. Additionally, the reevaluation may indicate an opportunity for Colorado to reevaluate provisions of the State program to more closely tailor its reclamation standards to fit the diverse environmental character of the State. Areas of potential emphasis may include:

Ensuring consideration of the distinct difference between surface and underground mining.

Revegetation success standards, including shrub density, species diversity and management practices.

Drainage control requirements.

Variances from approximate original contour requirements in steep-slope situations.

Geotechnical flexibility for disposal of excess overburden, underground development waste, and processing waste.

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TOOLS

DEVELOPMENT AND APPLICATION OF SOIL RESOURCE INFORMATION SYSTEMS

by

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LIST OF ACRONYMS

CORI - Catalog of Resource Information
CSU - Colorado State University
DBMS - Database Management System
EMRIA - Energy Mineral Rehabilitation Inventory and Analysis
PIN - Plant Information Network
SAGORIS - Soil and Geologic Overburden Resource Information System
SCS - Soil Conservation Service
SRIS - Soil Resource Information System

INTRODUCTION

Successful land management is dependent upon effective and rational decisionmaking, which is, in turn, largely dependent upon the availability of and access to accurate information.

An abundance of natural resource information already exists and more is being continually generated by State and Federal agencies, private industry, and research institutions. This information, however, is seldom utilized by persons other than those directly involved with its collection. This is due to a number of problems, including unavailability and inaccessibility of data, lack of data standardization and documentation and the lack of integration among related data sources. These problems result in a slowdown of the decisionmaking process, and costly duplication of effort as information is recollected.

Tilmann and Mokma (1980) stated that today's natural resource management problems require appropriate multisource data, as well as the means to effectively integrate these data, which can only be achieved through improved methods of information management. One such method involves the application of database technology to the development of computerized natural resource information systems. Database technology provides the mechanism through which data can be stored, integrated, and manipulated so that information can be easily and efficiently delivered to a diverse user community.

A number of hardware and software configurations are currently available for addressing data management needs. Any one or a number of these configurations may serve as the tool for managing a particular organization's information needs.

However, research is needed to determine the most effective manner of structuring and integrating data for utilizing database technology. More specifically, research can resolve questions pertaining to data structure, integration, accessibility, security, independence, shareability, reliability, integrity, administration, and other factors.

The purpose of this paper is to describe the development of two natural resource information systems by Colorado State University's (CSU) Department of Agronomy and Laboratory for Information Science in Agriculture (LISA).

PROJECT DESCRIPTIONS

Soil Resource Information System (SRIS)

Development of SRIS was initiated in 1979 under the sponsorship of the USDA Soil Conservation Service (U.S. Department of Agriculture 1979). The goal was to design, develop, and help implement a user-oriented information system which would: 1) recognize the types of user data needs; 2) determine the feasibility for integrating various types of soils information; and 3) serve as a mechanism for delivering soils information to a diverse user community.

The overall goal was to develop a prototype for the State of Colorado which would serve as a basis for selecting and implementing a soil resource information system.

Soil and Geologic Overburden Resource Information System (SAGORIS)

Development of SAGORIS was initiated in 1980 under the sponsorship of the USDI, Bureau of Land Management (BLM). The goal of the project was to design, develop, and test a prototype of a user-oriented information system with much the same functions as SRIS. SAGORIS, however, includes geologic overburden as well as soils information. The design and data content of SAGORIS are geared to the needs of those involved in mining-related activity. Consequently, the project emphasized data relating to the coal-bearing regions of the Western United States.

Catalog of Resource Information (CORI)

Development of this concept was initiated in 1981 as an internal research project. A CORI specific to the soils resource was developed as SAGORIS application for the BLM. In this application, the CORI functions as a geographic catalog to existing soil inventories. A pilot system was developed using the Powder River coal region of Montana and Wyoming as a study area.

INTRODUCTION TO DATABASE

Martin (1981) has stated that, "database technology is becoming increasingly important to data processing" and that it will be vital to the management of various entities in the future. To appreciate such a statement, an understanding of a few basic database concepts is necessary.

A "database" differs significanlty from computer-readable "data files," though both may contain the same collection of items. The difference between the two is not the data, but the way in which that data is stored, managed, and retrieved. The term "database" implies a collection of interrelated data stored to serve multiple purposes (Martin 1981). This is in contrast to individual data files which are not interrelated, in that each file may host a slightly different format, structure, or type of data. The primary function of such files is data storage. Unlike a database, separate data files are generated to serve different applications. Anderson (1982) further characterizes a database by the manner in which included data are handled. Data are stored independently of the programs which access them. A common and defined approach is used to add new data to the system and to retrieve it.

The term "database management system" (DBMS) refers to the software which supports the database. The DBMS serves to organize the data, controls access and retrieval of information from the database, and manipulates and integrates the data to provide specific information the user has requested. It is the DBMS which provides the flexibility to serve multiple applications which ordinary data files cannot effectively serve. It is also the DBMS which allows the nonexperienced user to personally interact with the data and retrieve information via the use of simple query language. In contrast, programming information out of data files requires the user to have a significantly higher level of computer expertise.

A number of computer and independent software companies manufacture DBMS's. Consequently, there are a variety of ways in which a database can be structured, depending upon user needs, desired applications, and features.

The term "information system" (as it is used here) refers to the databases, managed by the chosen DBMS, which have been designed to deliver information to the user.

RESEARCH AND DEVELOPMENT

A common approach was applied to the development of the two information systems and emphasized the following: 1) investigation of user needs, or analysis phase; 2) selection and evaluation of data for inclusion in the development of a pilot system; 3) DBMS selection; 4) pilot development; 5) pilot evaluation; and 6) prototype development and evaluation.

Investigation of User Needs

Input from potential users is critical in determining the design and data content of any information system. Personal interviews were conducted to establish contacts with potential users in both public agencies and private industry and to ascertain their information needs. A user mail survey was also conducted. Questionnaires enabled the development team to obtain inputs from a larger user audience than was possible through the interview process.

Potential users were questioned concerning data needs, sources, and applications. Problems typically associated with data availability, credibility, and format were identified. Interviewees and those contacted by questionnaire were introduced to the information system and asked to express what features, capabilities or components would be most useful to include in that system.

Selection and Evaluation of Data

Potential users of SRIS identified four major types of soils information commonly used in their decisionmaking: mapping unit, climatological, and pedon data and soils interpretations (Stevens et al. 1979). This information can be obtained from a number of different sources.

County or areawide soil survey reports, prepared by the SCS, are the primary source of mapping unit data. The National Pedon Data Subsystem, administered by the SCS and located in Lincoln, Nebraska, serves as the major source of site-specific pedon information. The primary source of soil series interpretations data is the Soils-5 Data File maintained at the Statistical Laboratory at Iowa State University, Ames, Iowa. This data file includes information pertaining to soil taxonomy and properties, suitability for community development, land capability classification, woodland and wildlife suitabilities, native plant community potential, and predicted yields for recognized soil series. Climatological data sources include summaries available from the National and State Weather Service reporting stations. These data include temperature and precipitation means and extremes, snow depth, precipitation intensities, probabilities, and cumulative totals. All of the aforementioned sources were used to obtain data for input to SRIS.

Potential users of SAGORIS identified a wide range of soils and geologic overburden information sources: mining and reclamation plans, EMRIA (Energy Minerals Rehabilitation Inventory and Analysis) reports (BLM), agency and privately conducted soil surveys, the National Pedon Data Subsystem, U.S. Geological Survey analytical data, regulatory agencies, geologic surveys and maps, and State climatological summaries (Stevens et al. 1981).

A number of problems typically encountered when using the aforementioned data sources were noted. Interviewees reported a lack of standardization in collection, analysis, and presentation of data; lack of correlation of soils data to published standards; insufficient detail for making management decisions; lack of reliable data; difficulty in identifying or locating available data; variable format of data; and lack of integration between various data sources.

Data sets were evaluated in light of these comments, prior to their inclusion in SAGORIS. Data set input to SAGORIS were obtained from mining and reclamation plans, EMRIA project reports, USDI Bureau of Reclamation inventories, the National Pedon Data Subsystem, and the Soils-5 Data File.

DBMS Selection

The DBMS chosen for the research and development of SRIS was System 2000® (MRI Systems Corporation, Austin, Texas), which was selected due to its availability on the CDC Cyber computer at the CSU Computer Center, Fort Collins. The DBMS is also available on the Univac computer at the USDA Fort Collins computer center. The USDA computer is a possible candidate to house a fully implemented SRIS.

System 2000 was also selected for use in the initial development of SAGORIS, again due to its availability. In addition, the use of the same DBMS for both information systems facilitated the interfacing of both databases in the future.

The DBMS chosen to implement CORI was SEED (International Data Base Systems, Philadelphia, Pennsylvania). SEED was selected due to its availability at CSU and because its software is highly compatible with the narrative format planned for the inventory catalog.

Pilot Development

A pilot system is a small-scale working model of the intended system, which contains a relativly small amount of data and is subject to possible alteration or revision. Pilot development involves designing the database structure, writing data entry and applications programs, and establishing data loading procedures.

The initial design of each project pilot, with respect to the types of data, components, features, and capabilities included, was in direct response to user needs. A list of data elements (such as pH, percent clay, extractable iron, etc.), was generated from an overview of the data sets to be included in the pilot systems. Data pertaining to each of these elements for each data set were transcribed onto data entry forms. These data were, in turn, interactively loaded into the respective database.

Pilot Evaluation

Completed pilot systems were evaluated by the project team and by interested users attending system demonstrations. A number of additional user needs were expressed in reaction to SRIS pilot demonstrations. These included: 1) the ability of the system to be accessed from remote locations; 2) capability to answer simple requests quickly; and 3) the ability to use the system by persons with little computer experience. Persons viewing the demonstrations felt the existing pilot structure addressed these needs satisfactorily. Additional responses to SRIS included the need for: 1) a centralized source of available soils data, 2) a centralized repository for data gathered by various data suppliers, 3) the ability to effect changes to erroneous or out-of-date information, and 4) the ability to access information from several different soils data sources. These features would be addressed by an operational SRIS not limited to the scope of a pilot system (Stevens et al. 1979).

The comments received following demonstration of the SAGORIS pilot system were similar to those stated for SRIS. In addition to these comments, persons viewing the demonstrations suggested the inclusion of additional data elements and expansion of the overburden portion of SAGORIS to include: 1) the capability of geographically locating bore holes by legal description; 2) identification of different laboratory analysis procedures; and 3) an interface with a statistical package to facilitate statistical analyses.

Prototype Development

A prototype is an operational model of the proposed system which contains a data set needed by a particular user group. The user group is trained to access the prototype to obtain information relevant to their needs. The group then evaluates how well the system provided the requested information. Feedback from prototype usage is necessary before full-scale implementation should be initiated.

Prototype development begins upon completion of the pilot evaluation. Differences between the pilot and prototype systems are a reflection of inputs made by those who viewed system demonstrations. Currently, each of the systems is at a different stage of prototype development.

GENERAL STRUCTURE

Conceptually, SRIS contains six components: soil map unit, plant and range, management, pedon, soils interpretations, and climatology. Figure 1 illustrates the relations among these components within SRIS. The components are linked under the control the DBMS System 2000.

The soil map unit component consists of attributes for the defined soil types of a given area. Attributes, or characteristics, include such items as map unit name, land capability classification, location, parent material, and potential crop yield. The map unit information is derived from published and unpublished SCS soil survey reports which generally correspond to individual counties.

The plant and range component consists of potential plant community data and specific information describing each range site in Colorado. The data include common and scientific names, poisonous plant designations, animal feeding preferences, and range site productivity. The plant and range site data are derived from the Plant Information Network (PIN; CSU) and SCS range site descriptions, respectively.

The management component contains narrative decriptions of land management practices and management alternatives for specific kinds of soils subject to similar climatic conditions.

The pedon component consists of site-specific information pertaining to selected taxonomic units. It includes chemical, physical, mineralogical, and engineering laboratory data generated at the National Soil Survey Laboratory for individual horizons of a given unit. The source of the pedon data is the SCS National Pedon Data Subsystem.

The soils interpretations component consists of information about the engineering properties of soil units and their limitations for various land uses. Included are such items as bulk density, shrink-swell potential, and ratings for building sites, recreational development, and wildlife habitat. The source of this information is the SCS Form-5 data records.

The final component, climatology, consists of climatological summaries representative of each map unit; also included are precipitation and temperature data. The source of this information is monthly reports published by the National Weather Service and the Colorado State Climatology Office.

The map unit and plant and range components of SRIS are developmentally the most advanced; both are operational prototypes. Figure 2 is a diagram of the map unit component structure, illustrating the grouping of related data items and relations among these groups. Currently loaded into the map unit portion is information for approximately 2,000 map units in 25 Colorado counties. Figure 3 illustrates the structure of the plant and range component. Currently loaded into this portion of SRIS is information pertaining to over 600 common plant species and over 100 range sites used in Colorado.

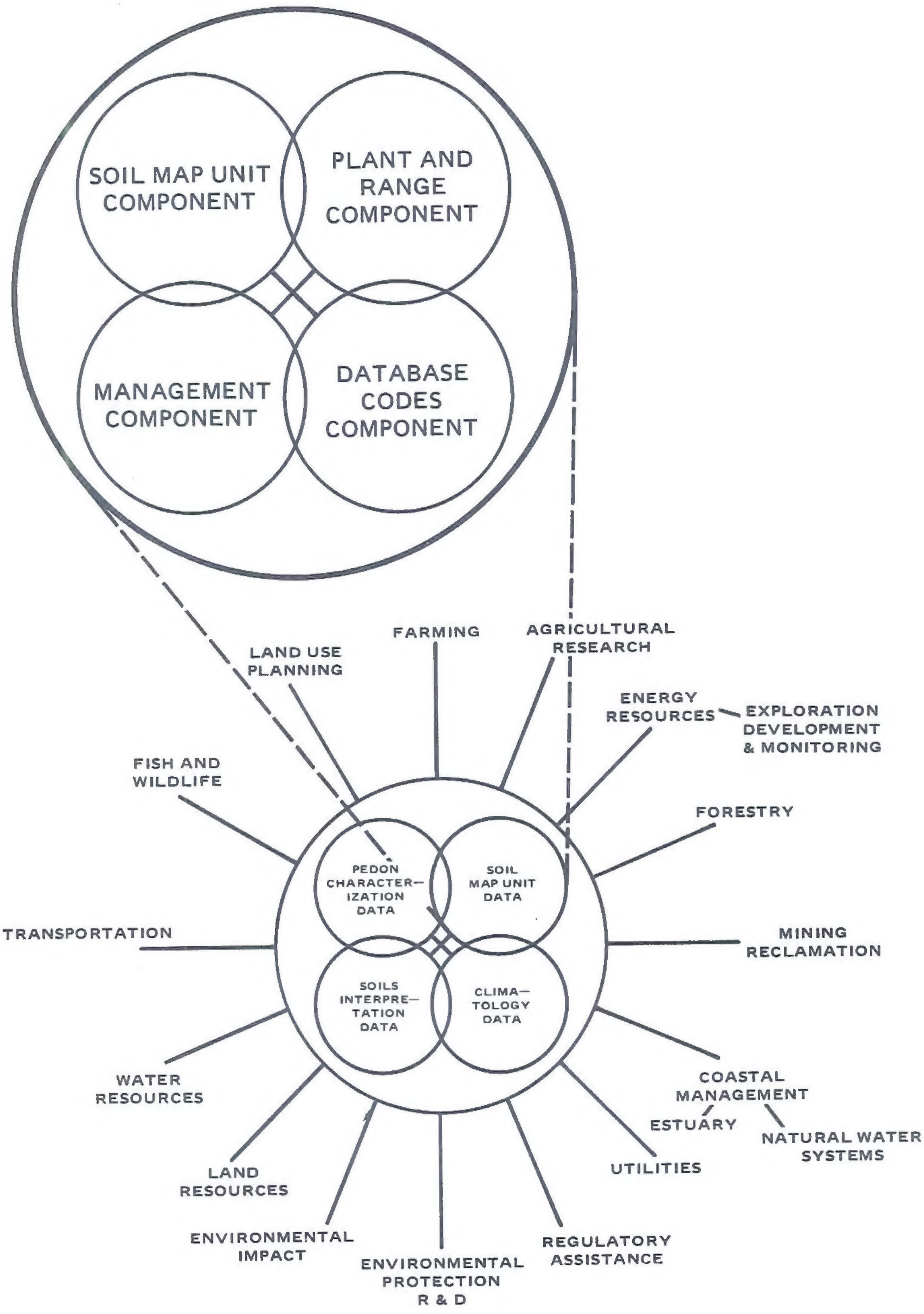


Figure 1. SRIS component diagram.

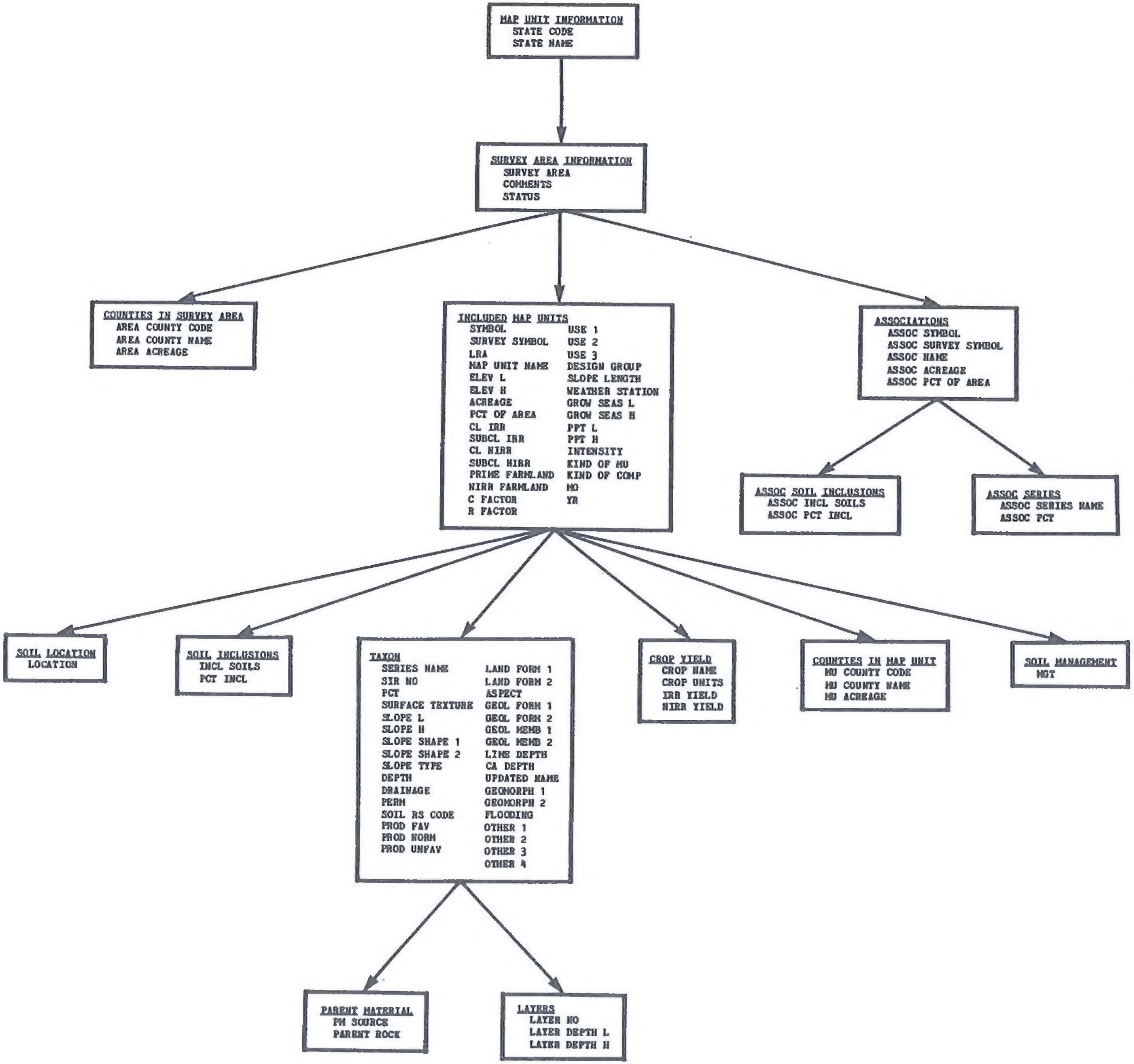


Figure 2. Map unit component structure.

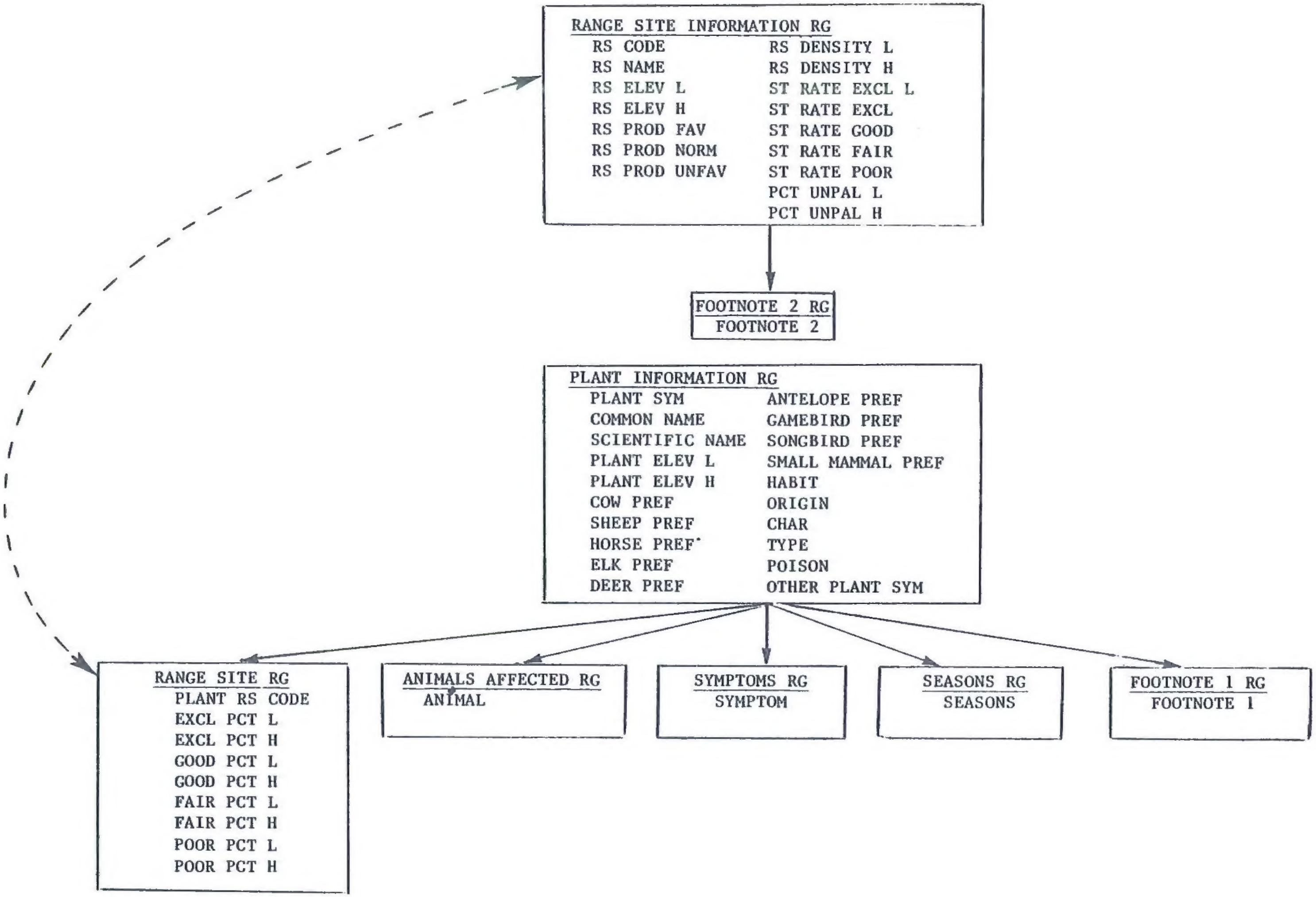


Figure 3. Plant and range component structure.

The soils interpretations component (Fig. 4) is in the pilot stage and currently contains information from approximatley 100 SCS soils interpretation records (Soils-5 data file).

The remaining SRIS components are also in the pilot stage, having been loaded with small sets of test data only. Data dictionaries describing data items in each component have been documented by Jukkola et al. (1980).

SAGORIS conceptually includes six components: geologic overburden, soil profile, soil map unit, analytical soils, soil series description, and soils interpretations. Data contained in the first four components are derived from mine permit applications, Bureau of Reclamation inventories, and BLM's EMRIA reports. The soils data are derived from inventories conducted on much smaller land areas than counties typically mapped by the SCS and consequently yields more detailed information.

The geologic overburden component consists of attribute information for individual core holes and greenhouse data for overburden samples tested as plant growth media. This component contains such items as log location, formation description, thickness of rock type and plant analysis.

The soil profile, map unit, and analytical components consist of related soils information. The soil profile component contains attribute information, including morphological, chemical, and physical data from individually sampled pedons. Horizon name, thickness, and structure are examples. The analytical component includes physical, chemical, and engineering laboratory data relating to sampled horizons of a given profile. Extractable molybdenum, acid-base potential, and sodium absorption ratio are examples. The map unit component relates to one or more of the sampled profiles and contains information pertaining to the location of the unit, its landscape position, and areal extent.

The soil series description component consists of information abstracted from SCS series description sheets for established series of common soil families in the Powder River coal region. Many of the included data items are similar to those of the soil profile component, particularly those pertaining to the physical attributes of the pedon. In addition, this component contains such information as associated soil series, geographic setting of the series, and the range in characteristics of the series.

The final SAGORIS component, soils interpretations, consists of information from the SCS Form-5 data records, from which those interpreations relevant to mined land reclamation are extracted and included as data items.

The most advanced of the six SAGORIS components is the geologic overburden component, presently in the prototype development stage (Fig. 5). Currently loaded into this component are greenhouse and laboratory data relating to overburden material sampled at two EMRIA sites in Montana and Colorado.

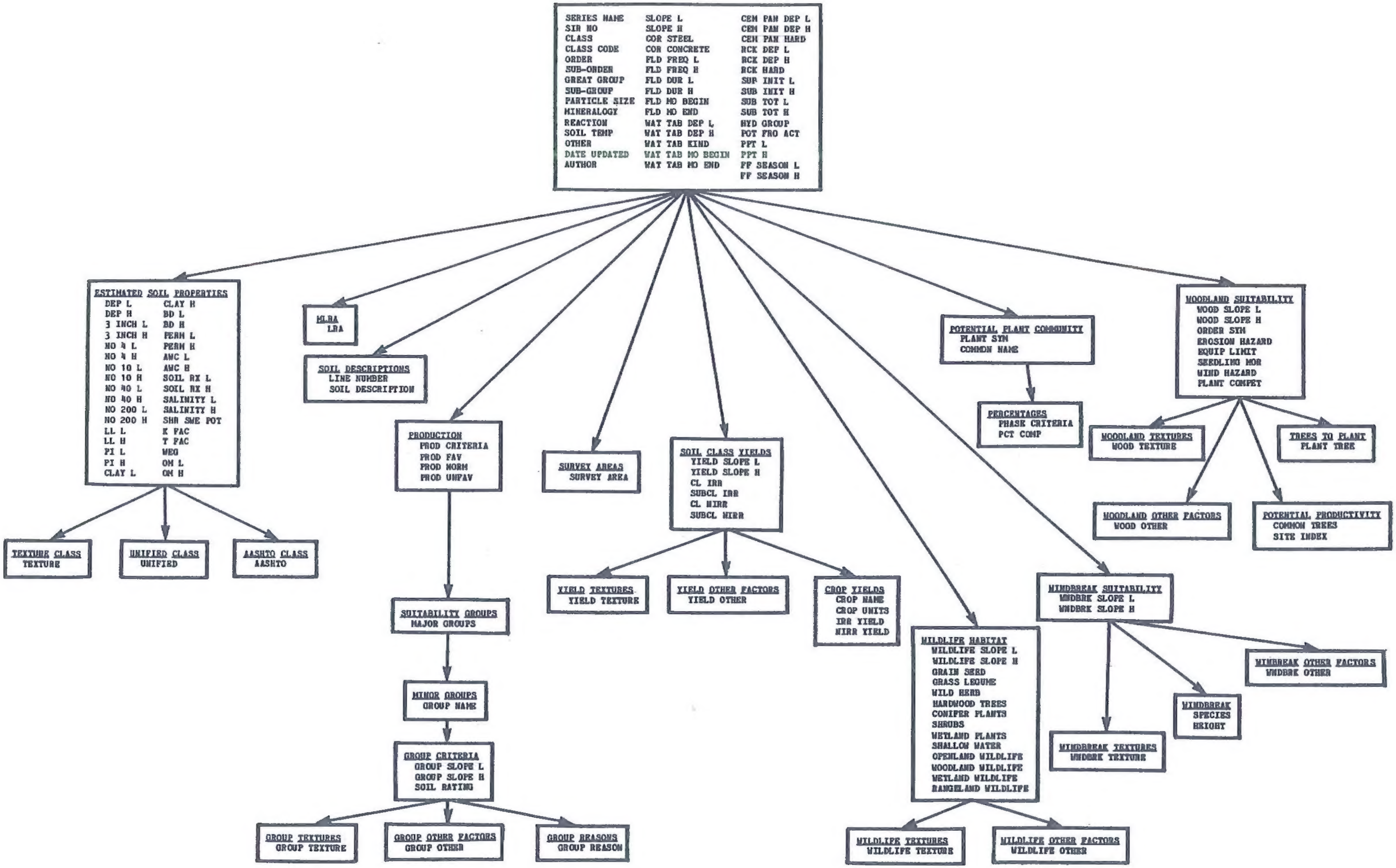


Figure 4. Soils interpretations component structure.

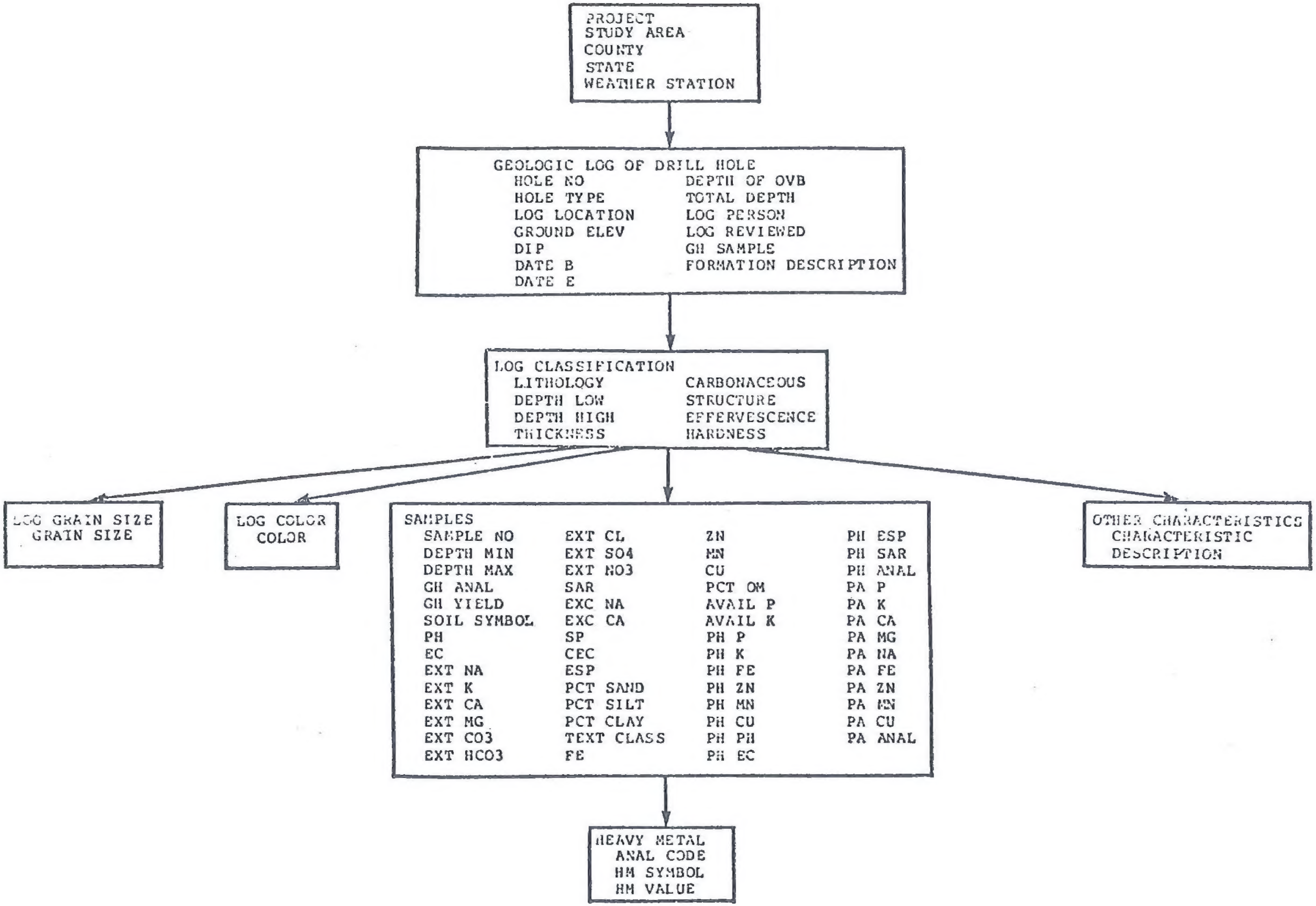


Figure 5. SAGORIS structure diagram.

Pilot development has been initiated on the remaining components of SAGORIS. When this phase is completed, the database will contain site-specific soils information from a number of mine permit applications, EMRIA reports, and Bureau of Reclamation inventories.

CORI conceptually consists of a series of records describing natural resources documents. Each record contains such information as title, date of publication, type of data, included maps, and, in the case of documents containing soil surveys, survey intensity, correlation status, and surveyed acreage.

CORI development is nearing completion. The system presently includes detailed descriptions of over 40 documents containing soil inventories conducted within the Powder River Basin. Documents include SCS soil surveys, Bureau of Reclamation inventories, mine permit applications, environmental impact statements, and miscellaneous research reports.

CAPABILITIES AND APPLICATIONS

Many capabilities of a fully developed SRIS, SAGORIS, or CORI are not unique to these systems but are characteristics of automated information systems in general. Among the most useful of these is the ability to access a large database from a remote location using minimal equipment: terminal, modem, and telephone. Telephone hook-ups enable a user to be in direct contact with the system in the time it takes to place a phone call.

Data identified as being either incorrect or outdated can be easily corrected within a database. Making corrections is not constrained by reprinting and publication time; once the editing is complete, the corrected or updated information is immediatley accessible.

Data stores, previously residing at scattered locations, can be centralized and linked in an automated information system. This feature significantly reduces the time and costs associated with making formal requests for information and then awaiting its arrival.

Users with little or no computer exprience can interact directly with the database through the use of simple, structured English query language. The user is not forced to glean desired information from pages of extraneous data; rather, the user can structure ad-hoc questions to obtain selected information.

Presently, SRIS and SAGORIS are capable of responding to an infinite number of ad-hoc inquiries. In addition, a number of applications programs have been written and incorporated into the information systems (Stevens *et al.* 1980, Jukkola *et al.* 1980, Stevens *et al.* 1981). These applications are unique to SRIS and SAGORIS and directly reflect the information needs expressed by people interviewed and consulted throughout system development.

The information-generating capabilities of the systems have not been exhaustively investigated. The kinds of applications and capabilities may be more limited by the user's lack of knowledge about the data and inability to ask the proper questions than by limitations of the system in handling the posed questions.

Significant progress has been made toward developing a prototype of each system. Fully tested prototypes will serve as a basis for selecting and implementing an information system that can easily, efficiently, and economically deliver information to a diverse user community.

Figures 6 and 7 are sample SRIS information retrievals. Each sample is structured to include the question posed to SRIS, the feasibility of the question, the query command(s) used to pose the question, and the SRIS response. In these examples, the lower case type was entered by the user; the upper case type is output by SRIS.

A number of applications programs have been written and incorporated into SRIS in response to comments from soils information users. Figure 8 depicts a set of computer-generated tables which group soils of Yuma County, Colorado, according to their suitabiity for chemical fallow. The program which produced this information accessed data from the map unit component of SRIS. A short narrative explaining the suitability ratings can also be generated from SRIS but is not included here.

Data from SRIS can be easily interfaced with statistical packages (see Figs. 9 and 10). The scatterplot and regression analysis summaries were produced by MINITAB, an interactive statistical package (Ryan et al. 1976). A data file containing percent sand, silt, clay, organic carbon, and 15-bar percent water by horizon depth was generated from the pedon component of SRIS. This file was copied, transferred to the MINITAB software package, and executed.

Figures 11 and 12 are sample SAGORIS information retrievals. The format is the same as for the SRIS samples.

SAGORIS incorporates an application program which determines the suitability of soil and/or geologic overburden as plant growth media. The table presented in Figure 13 was generated from data included in the overburden component of SAGORIS. Data for each sample were compared with published standards for critical levels of pH, SAR, salinity, texture class, etc., to determine suitability for plant growth. In this example, unacceptable samples are identified along with their lithology, depth range of the lithologic unit, and charcteristics that limit their use as plant growth media. A relative suitability rating is assigned.

Figures 14, 15 and 16 are samples of output obtained from CORI, showing how a particular document is "located" for listing. A user interested in soil survey information for a particular township can obtain a list of all relevant documents by simply entering the township and range. Similarly, relevant documents can be located through county name, state name, or author name. Figure 15 is output describing the soils portion of a mine permit application. Figure 16 is output describing an unpublished soil survey.

QUESTION: List the soil Map Units in Kiowa County that are developing in material from calcareous shales (the Pedon code for calcareous shales is H2). What is the total acreage and percent of the survey area occupied by these soils?

FEASIBILITY: This would be a question of interest to Agronomists, Soil Scientists, Geologists, Reclamation Specialists, and Engineers. Soils developing in shales often exhibit inherent properties which affect their uses. Water quality is also affected by lithology. Knowing the extent of these soils could be very helpful in planning.

```
---
? list map unit name, sum acreage, sum pct of area
---
? where parent rock eq h2 and survey area eq kio;
  MAP UNIT NAME                         SUM ACREAGE   SUM PCT OF AREA
***
* ABSTED CLAY,0 TO 1 PCT SLOPES               89704             7.700
* ARVADA-ABSTED CLAYS, 0 TO 2 PCT SLO
  PES
* CADOMA CLAY, 1 TO 8 PCT SLOPES
* LIMON CLAY
* MANZANOLA CLAY LOAM, 0 TO 2 PCT SLO
  PES
* MIDWAY CLAY, 5 TO 12 PCT SLOPES
```

Figure 6. Sample SRIS query and system response.

QUESTION: List the plants which represent the potential plant community on Dalhart Loamy Sand, 1 to 3 pct slopes (symbol "DAB") in Baca county.

FEASIBILITY: This information is of importance to Range Scientists, Soil Conservationists, Wild Life Ecologists, and Soil Scientists in planning, management, and determining production potential.

This question must be answered in two steps. First we need to know what range site has been correlated with Dalhart Loamy Sand, 1 to 3 pct slopes, in Baca County. To obtain this information, we ask the query as follows.

```
---
? list soil rs code where survey area eq bac and symbol eq dab;
  SOIL RS CODE
***
* SP24
```

Knowing that the Range Site code of the soil is "SP24" (from the Map Unit portion of the data base) the desired information for this specific Range Site can be obtained as follows (using the Plant and Range Information portion of the data base).

```
---
? list common name, scientific name, pct l, pct h where
---
site code eq sp24;
  COMMON NAME             SCIENTIFIC NAME               PCT L   PCT H
***
* BLUE GRAMA              BOUTELOUA GRACILIS               20      25
* LITTLE BLUESTEM         SCHIZACHYRIUM SCOPARIUM           5      10
* NEEDLEANDTHREAD         STIPA COMATA (2)                  5      10
* PRAIRIE JUNEGRASS       KOELERIA CRISTATA                 3       5
* PRAIRIE SANDREED        CALAMOVILFA LONGIFOLIA           25      30
* SAND BLUESTEM           ANDROPOGON HALLII                 5      10
* SAND DROPSEED           SPOROBOLUS CRYPTANDRUS            1       5
* SIDEOATS GRAMA          BOUTELOUA CURTIPENDULA           10      15
* SUN SEDGE               CAREX HELIOPHILA                  1       5
* SWITCHGRASS             PANICUM VIRGATUM                  5      10
* THICKSPIKE WHEATGRAS    AGROPYRON DASYSTACHYUM (2         5      10
  S                       ) VAR DASYSTACHYUM
                                  .
                                  .
```

Figure 7. Sample SRIS query and system response.

```
                    ESTIMATED SOIL POTENTIAL FOR CHEMICAL FALLOW     PAGE   1
                               FOR YUM SURVEY AREA

                            SOIL CONSERVATION SERVICE

             SOIL MAP UNITS WITH GOOD     POTENTIAL FOR CHEMICAL FALLOW
----------------------------------------------------------------------------
    MAP UNIT NAME                                      SYMBOL ACREAGE
----------------------------------------------------------------------------
    ALBINAS LOAM                                       1        10700
    ASCALON FINE SANDY LOAM, 0 TO 3 PCT SLOPES         5        45800
    BAYARD FINE SANDY LOAM, 2 TO 6 PCT SLOPES          7        10700
    HAXTUN SANDY LOAM                                  19       71700
    KUMA-KEITH SILT LOAMS                              25      152500
    PAOLI SANDY LOAM                                   32        3000
    PLATNER LOAM                                       35       45800
    RAGO CLAY LOAM, OCCASIONAL OVERFLOW                38        4600
    RAGO LOAM                                          37       38100
    RICHFIELD SILT LOAM                                40       10700

                               .
                               .
                               .

                    ESTIMATED SOIL POTENTIAL FOR CHEMICAL FALLOW     PAGE   2
                               FOR YUM SURVEY AREA

                            SOIL CONSERVATION SERVICE

             SOIL MAP UNITS WITH FAIR     POTENTIAL FOR CHEMICAL FALLOW
----------------------------------------------------------------------------
    MAP UNIT NAME                                      SYMBOL ACREAGE
----------------------------------------------------------------------------
    ASCALON LOAMY SAND, 3 TO 9 PCT SLOPES              2         4600
    ASCALON SANDY LOAM, 3 TO 5 PCT SLOPES              3        19800
    ASCALON SANDY LOAM, 5 TO 9 PCT SLOPES              4         1500
    ECKLEY GRAVELLY SANDY LOAM, 3 TO 7 PCT SLOPES      15        3000
    HAXTUN LOAMY SAND                                  18       85400
    ILIFF LOAM                                         20        7600
    JULESBURG LOAMY SAND, 0 TO 3 PCT SLOPES            22       54900
    MANTER LOAMY SAND                                  29       35100
    MANTER SANDY LOAM, 2 TO 5 PCT SLOPES               30       23400
    MANTER SANDY LOAM, 5 TO 9 PCT SLOPES               31       12600
    PLATNER SANDY LOAM, 3 TO 5 PCT SLOPES              34        3000
    STONEHAM LOAM                                      41        1500
    VONA LOAMY SAND                                    47       13700
```

Figure 8a. Output from SRIS application program.

```
                ESTIMATED SOIL POTENTIAL FOR CHEMICAL FALLOW      PAGE   3
                           FOR YUM SURVEY AREA

                        SOIL CONSERVATION SERVICE

          SOIL MAP UNITS WITH POOR     POTENTIAL FOR CHEMICAL FALLOW
---------------------------------------------------------------------------
   MAP UNIT NAME                                       SYMBOL ACREAGE
---------------------------------------------------------------------------
   COLBY SILT LOAM, 3 TO 6 PCT SLOPES                   10       44200
   GLENBERG-BANKARD COMPLEX                             16        1500
   HAVERSON LOAM                                        17        7600
   JULESBURG LOAMY SAND, 3 TO 7 PCT SLOPES              23       62500
   KIM LOAM, 3 TO 6 PCT SLOPES                          24        1500
   LAIRD FINE SANDY LOAM                                26        6100
   LAS ANIMAS FINE SANDY LOAM                           27        4600

                              .
                              .
                              .

                ESTIMATED SOIL POTENTIAL FOR CHEMICAL FALLOW      PAGE   4
                           FOR YUM SURVEY AREA

                        SOIL CONSERVATION SERVICE

          SOIL MAP UNITS WITH UNSUITED POTENTIAL FOR CHEMICAL FALLOW
---------------------------------------------------------------------------
   MAP UNIT NAME                                       SYMBOL ACREAGE
---------------------------------------------------------------------------
   BANKARD SAND                                         6        10700
   CANYON-DIOXICE COMPLEX, 1 TO 9 PCT SLOPES            8         5200
   CANYON-ROCK OUTCROP COMPLEX                          9        45800
   COLBY SILT LOAM, 6 TO 15 PCT SLOPES                  11       85400
   COLBY-TORRIORTHENTS COMPLEX, GULLIED, 15 TO 25 PCT   12       41200
   DAILEY LOAMY SAND                                    13       10700
   DWYER-VONA LOAMY SANDS, 3 TO 9 PCT SLOPES            14        4600
   INAVALE LOAMY SAND                                   21        4600
   LAS ANIMAS LOAM                                      28        1500
   PITS                                                 33         300
   PLATTE FINE SANDY LOAM                               36        3000
   RAZOR-MIDWAY COMPLEX, 3 TO 9 PCT SLOPES              39        3000
   TERRY LOAMY SAND                                     42        1500
   VALENT SAND, 1 TO 9 PCT SLOPES                       43      259300
   VALENT SAND, 15 TO 45 PCT SLOPES                     45       27500
   VALENT SAND, 9 TO 15 PCT SLOPES                      44      227200
   VALENT-BLOWNOUT LAND COMPLEX, 1 TO 25 PCT SLOPES     46        3000
```

Figure 8b. Output from SRIS application program (continued).

```
print c1-c5
 COLUMN     SAND        SILT        CLAY       ORG-C       DEPTH
 COUNT         7           7           7           7           7
 ROW
   1     87.8000     6.60000      5.6000     .280000          3.
   2     84.0000     5.70000     10.3000     .340000          8.
   3     85.8000     4.80000      9.4000     .210000         14.
   4     86.3000     5.50000      8.2000     .130000         25.
   5     90.8000     3.80000      5.4000     .040000         39.
   6     90.6000     4.30000      5.1000     .020000         53.
   7     93.6000     1.80000      4.6000     .020000         68.

 --
? mplot c5 vs c1, c5 vs c2, c5 vs c3
             DEPTH
              75.+
                 -
                 -  BC                                            A
                 -
                 -
              60.+
                 -
                 -   BC                                         A
                 -
                 -
              45.+
                 -
                 -   BC                                         A
                 -
                 -
              30.+
                 -
                 -    BC                                      A
                 -
                 -
              15.+   B  C                                     A
                 -
                 -    B C                                    A
                 -
                 -    2                                        A
               0.+
                   +---------+---------+---------+---------+---------+SAND
                  0.                 40.                 80.
                           20.                 60.                100.
```

Figure 9. Sample MINITAB output generated using SRIS data as input.

```
print c1, c2, c3
 COLUMN CLAY-PCT        15-BAR        ORG-C
 COUNT         7             7            7
 ROW
   1      5.6000       2.50000      .280000
   2     10.3000       3.70000      .340000
   3      9.4000       3.70000      .210000
   4      8.2000       3.20000      .130000
   5      5.4000       2.20000      .040000
   6      5.1000       2.10000      .020000
   7      4.6000       1.90000      .020000

 --
? regress c2 on 2 predictors in c1, c3

 THE REGRESSION EQUATION IS
 Y =    .554 +  .306 X1 +  .522 X2

                                             ST. DEV.     T-RATIO =
        COLUMN      COEFFICIENT              OF COEF.     COEF/S.D.
        --                 .554                  .198          2.80
 X1     CLAY-PCT          .3062                 .0354          8.65
 X2     ORG-C              .522                  .624           .84

 THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 S =        .140
 WITH (   7- 3) =   4 DEGREES OF FREEDOM

 R-SQUARED = 97.8 PERCENT
 R-SQUARED = 96.7 PERCENT, ADJUSTED FOR D.F.

 ANALYSIS OF VARIANCE

  DUE TO       DF          SS         MS=SS/DF
 REGRESSION     2      3.4392          1.7196
 RESIDUAL       4       .0779           .0195
 TOTAL          6      3.5171

 FURTHER ANALYSIS OF VARIANCE
 SS EXPLAINED BY EACH VARIABLE WHEN ENTERED IN THE ORDER GIVEN

  DUE TO       DF          SS
 REGRESSION     2      3.4392
 CLAY-PCT       1      3.4256
 ORG-C          1       .0136

             X1          Y      PRED. Y    ST.DEV.
 ROW   CLAY-PCT     15-BAR       VALUE    PRED. Y    RESIDUAL        ST.RES.
   1        5.6      2.500       2.415       .132        .085         1.85 X

 X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.
```

Figure 10. Sample MINITAB output generated using SRIS data as input.

Question - What is the total thickness and depth range of materials classified as having a coal lithology in bore hole number 79-107.

Feasibility - This type of information would be of interest to land managers and mine operators in identifying total coal deposits at a given point and in identifying the depth at which these coal deposits are located.

```
 ---
? list sum thickness where lithology eq coal and hole no eq 79-107;
   SUM THICKNESS
 ###
 *        67.000
 ---
? list lithology, depth low, depth high where same;
   LITHOLOGY                DEPTH LOW   DEPTH HIGH
 ###
 * COAL                         47.00        58.00
 * COAL                         79.00        85.00
 * COAL                        130.80       133.40
 * COAL                        148.40       149.80
 * COAL                        267.00       312.20
 * COAL                        328.30       329.10
```

Question - List the total thickness of the coal deposits located above a depth of 150 feet in bore hole number 79-110.

Feasibility - This information would be of interest to mine operators and land managers who need to determine the amount of recoverable coal above a given depth.

```
 ---
? list sum thickness where depth high le 150. and lithology eq coal and
 ---
? hole no eq 79-110;
   SUM THICKNESS
 ###
 *        32.500
```

Figure 11. Sample SAGORIS queries and system response.

Question - List, for all the core logs of EMRIA site number 21, those samples which have exchangeable sodium percentages greater than 15 percent. Identify these samples by hole number, lithology, sample number and depth range.

Feasibility - This type of information can be used by land managers in identifying zones of material which have the potential for possible sodium problems.

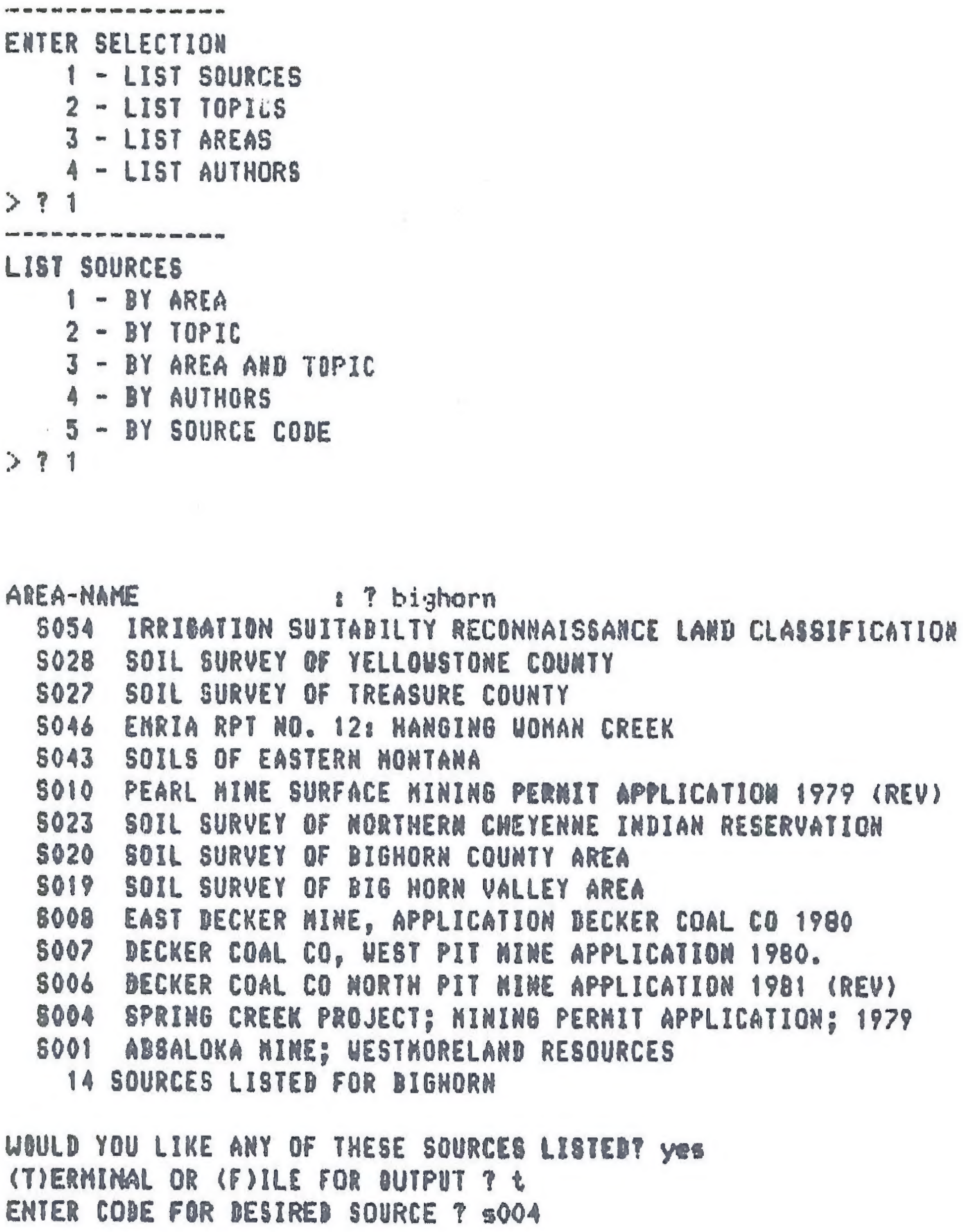
```
 ---
? list hole no, lithology, sample no, depth min, depth max, esp,
 ---
? ordered by high lithology where esp gt 15. and project eq emria 21;
   HOLE NO   LITHOLOGY                SAMPLE NO   DEPTH MIN  DEPTH MAX      ESP
 ***
 * 79-107    SILTSTONE                79-107-18       258.5      267.0     20.0
 * 79-110    SHALE                    79-110-6        143.5      150.0     17.0
 * 79-107    SANDY SILTSTONE          79-107-15       191.3      211.6     30.0
 * 79-110    SANDY SHALE              79-110-4         75.0       86.2     20.0
 *                                    79-110-3         50.0       75.0     17.0
 * 79-107    SANDSTONE W/ CLAYEY      79-107-13       173.3      184.2     38.0
             SANDSTONE
 *           SANDSTONE                79-107-11       149.8      163.6     19.0
 *           SANDSTONE                79-107-16       211.6      234.0     30.0
 *           SANDSTONE                79-107-12       163.0      173.3     32.0
 *           CARBONACEOUS SHALE       79-107-10       139.8      148.4     28.0
 *           CARBONACEOUS SHALE       79-107-14       184.2      191.3     22.0
```

Figure 12. Sample SAGORIS queries and system response.

SAGORIS Application Listing

```
-------------------------------------------------------------------------------------------------------
        PROJECT:EMRIA 21                BLM PLANT GROWTH SUITABILITY      HOLE NUMBER:79-107       PAGE  1
-------------------------------------------------------------------------------------------------------

SAMPLE NUMBER  LITHOLOGY           MIN DEPTH  MAX DEPTH  CHARACTERISTIC        VALUE   RATING
-------------  ---------           ---------  ---------  ----------------      -----   ------
79-107-1       SANDY SHALE               0.0       18.5  TEXTURE CLASS         SICL    FAIR
                                                         AVAILABLE PHOSPHORUS   1.00   DEFICIENT
                                                         SALINITY               4.60   MARGINAL

79-107-2       CLAYEY SANDSTONE         18.5       33.0  TEXTURE CLASS         CL      FAIR
                                                         AVAILABLE PHOSPHORUS   1.00   DEFICIENT

79-107-3       SANDY SHALE              33.0       44.0  AVAILABLE PHOSPHORUS   1.00   DEFICIENT

79-107-4       SILTSTONE                44.0       64.0  AVAILABLE PHOSPHORUS   1.00   DEFICIENT
                                                         SALINITY               4.37   MARGINAL

79-107-5       SILTSTONE                64.0       79.0  TEXTURE CLASS         SICL    FAIR
                                                         AVAILABLE PHOSPHORUS   4.00   DEFICIENT
                                                         SALINITY               4.80   MARGINAL

79-107-6       SANDSTONE                85.0       92.6  TEXTURE CLASS         CL      FAIR
                                                         PH                     3.80   POOR
                                                         SALINITY               8.87   POOR TO UNSUITABLE

79-107-7       SANDSTONE                92.6      104.0  AVAILABLE PHOSPHORUS   1.00   DEFICIENT
                                                         AVAILABLE POTASIUM    54.00   DEFICIENT
                                                         SALINITY               5.68   MARGINAL

79-107-8       SANDSTONE               104.0      121.0  AVAILABLE PHOSPHORUS   1.00   DEFICIENT
                                                         AVAILABLE POTASIUM    24.00   DEFICIENT

79-107-9       CARBONACEOUS SHALE      124.0      139.8  TEXTURE CLASS         SIC     POOR
                                                         SALINITY               8.40   POOR TO UNSUITABLE

79-107-10      CARBONACEOUS SHALE      139.8      148.4  TEXTURE CLASS         SIC     POOR
                                                         SALINITY               5.90   MARGINAL
                                                         SODIUM                28.00   NON-ACCEPTABLE

79-107-11      SANDSTONE               149.8      163.6  TEXTURE CLASS         SIC     POOR
                                                         SALINITY               7.58   MARGINAL
                                                         SODIUM                19.00   NON-ACCEPTABLE

79-107-12      SANDSTONE               163.0      173.3  SALINITY               4.24   MARGINAL
                                                         SODIUM                32.00   NON-ACCEPTABLE

79-107-13      SANDSTONE W/ CLAYEY     173.3      184.2  SODIUM                38.00   NON-ACCEPTABLE

79-107-14      CARBONACEOUS SHALE      184.2      191.3  TEXTURE CLASS         SIC     POOR
                                                         SODIUM                22.00   NON-ACCEPTABLE

79-107-15      SANDY SILTSTONE         191.3      211.6  TEXTURE CLASS         SICL    FAIR
                                                         SODIUM                30.00   NON-ACCEPTABLE

79-107-16      SANDSTONE               211.6      234.0  SODIUM                30.00   NON-ACCEPTABLE
```

Figure 13. Output from SAGORIS application program.



```
---------------
ENTER SELECTION
    1 - LIST SOURCES
    2 - LIST TOPICS
    3 - LIST AREAS
    4 - LIST AUTHORS
> ? 1
---------------
LIST SOURCES
    1 - BY AREA
    2 - BY TOPIC
    3 - BY AREA AND TOPIC
    4 - BY AUTHORS
    5 - BY SOURCE CODE
> ? 1


AREA-NAME             : ? bighorn
  S054  IRRIGATION SUITABILTY RECONNAISSANCE LAND CLASSIFICATION
  S028  SOIL SURVEY OF YELLOWSTONE COUNTY
  S027  SOIL SURVEY OF TREASURE COUNTY
  S046  ENRIA RPT NO. 12: HANGING WOMAN CREEK
  S043  SOILS OF EASTERN MONTANA
  S010  PEARL MINE SURFACE MINING PERMIT APPLICATION 1979 (REV)
  S023  SOIL SURVEY OF NORTHERN CHEYENNE INDIAN RESERVATION
  S020  SOIL SURVEY OF BIGHORN COUNTY AREA
  S019  SOIL SURVEY OF BIG HORN VALLEY AREA
  S008  EAST DECKER MINE, APPLICATION DECKER COAL CO 1980
  S007  DECKER COAL CO, WEST PIT MINE APPLICATION 1980.
  S006  DECKER COAL CO NORTH PIT MINE APPLICATION 1981 (REV)
  S004  SPRING CREEK PROJECT; MINING PERMIT APPLICATION; 1979
  S001  ABSALOKA MINE; WESTMORELAND RESOURCES
    14 SOURCES LISTED FOR BIGHORN

WOULD YOU LIKE ANY OF THESE SOURCES LISTED? yes
(T)ERMINAL OR (F)ILE FOR OUTPUT ? t
ENTER CODE FOR DESIRED SOURCE ? s004
```

Figure 14. CORI information retrieval sequence, beginning with selection option.

```
--------------------------------------------------------------------------------
                82/03/02.    C.O.R.I. OUTPUT     15.17.00.
--------------------------------------------------------------------------------

    SOURCE CODE: S041                  SOURCE NUMBER:
    TITLE: SOIL SURVEY OF CUSTER COUNTY
    RESPONSIBLE AGENCY: SOIL CONSERVATION SERVICE
    TYPE OF SOURCE: GENINT           SOURCE IS UNPUBLSHED
    DATE OF PUBLICATION: UNKNOWN
    STATUS OF SOURCE:
         INCOMPLETE     DATE BEGAN:               COMPLETION DATE:
    SOIL CLASSIFICATION SYSTEM USE: SOIL TAXONOMY
    SURVEY TYPE                   : PROGRESSIVE
    THE FOLLOWING MAPS HAVE BEEN INCLUDED IN THIS SOURCE:
    AUTHORS:
         SETERA         , JEROME         ; SOIL CONSVN. SE FROM MONTANA
    COLLECTORS:
    BRIEF     : UNPUBLISHED SOIL SURVEY. AS OF 1/82, DETAILED
              : SURVEYING COMPLETED ON THE FOLLOWING: PARTS OF
              : T13N,R45E;T13,R46E;T12N,R45E;T12N,R46E;T10N,R49E;
              : T10N,R50E;T9N,R46E;T9N,R47E;T9N,R49E;T9N,R50E;
              : T9N,R51E;T8N,R46E;T8N,R50E;T7N,R46E;T7N,R50E;
              : T6N,R46E;T6N,R47E;T6N,R49E;T5N,R47E;T5N,R48E;
              : T5N,R49E;T4N,R47E;T4N,R48E;T2N,R45E;T2N,R46E;
              : T1N,R47E;T1N,R48E;T1N,R49E;T1N,R50E; AND ALL OF
              : T9N,R48E;T8N,R47E;T8N,R48E;T8N,R49E;T7N,R47E;
              : T7N,R48E;T7N,R49E;T6N,R48E.
    CONTACTS:
         USDA SOIL CONSERVATION SERVICE
         32 E. BABCOCK
         BOZEMAN, MT
         59715

    THIS SOURCE PERTAINS TO THE FOLLOWING TOPICS:
```

Figure 15. Sample CORI output.

```
--------------------------------------------------------------------------------
              82/03/02.     C.O.R.I. OUTPUT      15.17.00.
--------------------------------------------------------------------------------

   SOURCE CODE: S004                  SOURCE NUMBER:
   TITLE: SPRING CREEK PROJECT; MINING PERMIT APPLICATION; 1979
   RESPONSIBLE AGENCY: NORTHERN ENERGY RESOURCES; SPRING CREEK COAL CO.
   TYPE OF SOURCE: GENINT            SOURCE IS PUBLISHED
   DATE OF PUBLICATION: 1979-REV
   STATUS OF SOURCE:
        COMPLETE       DATE BEGAN: 1975          COMPLETION DATE: 1976
   ACREAGE                         : 8880
   NCSS CORRELATION STATUS         : UNCORRELATED
   SURVEY ORDER OR INTENSITY       : 1
   INITIAL MAPPING SCALE           : 1:4800
   SURVEY TYPE                     : REQUESTED
   MAPPING UNIT DESC               : ALL
   SOIL PROFILE DESC AVAIL         : ALL
   THE FOLLOWING MAPS HAVE BEEN INCLUDED IN THIS SOURCE:
        SOILS MAP,SPRNG CRK , MAP TYPE: SOIL      , MAP SCALE: 1:4800
   AUTHORS:
        UNKNOWN         ,                ; VTN ENV CONSULT FROM DENVER CO
   COLLECTORS:
        MOSIER          , RON            ; CONSULTANT      FROM BILLINGS MT
        WALSH           , JAMES          ; VTN ENV. CONSUL FROM DENVER
   BRIEF     : THIS IS A MINE APPLICATION SOIL SURVEY WHICH IS NOT
             : CORRELATED. ESTABLISHED SOIL SERIES NAMES ARE USED
             : WHERE POSSIBLE. THE PURPOSE FOR DATA COLLECTION WAS
             : FOR A MINE APPLICATION AND A RECLAMATION PLAN.
   CONTACTS:
        DEPT OF STATE LANDS; MONTANA     NERCO INC.
        CAPITOL STATION                  529 SW THIRD AVE.
        HELENA, MT.                      PORTLAND, OR.
        59601                            97204

   THIS SOURCE PERTAINS TO THE FOLLOWING TOPICS:
        SOIL
        FOR THIS TOPIC, THE FOLLOWING DATA FORMATS EXIST
        > RAW DATA
        > SUPPORTING ANALYTICAL DATA
                  PH   , EC   , SAT  , PSA  , CA   , MG   , NA   , SAR
                  BO   , K    , CEC  , ESP  ,
```

Figure 16. Sample CORI output.

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NATURAL RESOURCE APPLICATIONS OF REMOTE SENSING

by

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INTRODUCTION

Current demands for natural resources in the West require that land managers be able to rapidly assess potential and immediate impacts of environmental modification over large land areas. Remote sensing techniques are routinely used as a tool to facilitate resource evaluations and assessments.

Remote sensing encompasses the techniques of aerial photography and imagery, thermal scanning, and airborne radar. Aircraft and satellites take photographs or record electromagnetic radiation with other devices to produce images of the earth. The interpretation of the images, whether on film, videotape, or some other medium, has become a highly technical and specialized science.

Since the demise of the National Aeronautics and Space Administration (NASA), much of the technology and expertise previously concentrated on the space effort has been shifted to the development, use, and promotion of remote sensing techniques. Unfortunately, many of the techniques which have been developed require electronic equipment for image processing which is beyond the cost and technical training of most resource specialists. As Meyer and Maklin (1969) state,

> ... deluged as one is these days with all the glitter and glamour of remote sensing vehicles; sophisticated (expensive) hardware, generous capability claims and a burgeoning (somewhat unintelligible) technical language, the necessity for economic practical application is somewhat overlooked.

Fortunately, sophisticated electronic gadgetry and in-house computer capability is not a prerequisite to applying remote sensing techniques. With a minimum of equipment and some working knowledge of photogrammetry, it is possible for resource managers to utilize remote sensing techniques to increase the efficiency and accuracy of their work. It is the intent of this paper to focus on techniques and materials which have relevance to the Fort Union region and which are financially and technologically within the realm of field level resource people.

Meyer and Gerbig (1974) conducted a forest and range resource survey in the Malta District (Bureau of Land Management), Montana, with objectives clearly aimed at practical use by the person in the field. Their description of how remote sensing techniques would extend the capabilities of resource managers is well stated. They state that remote sensing:

1) Permits the gathering of resource management data of technical or biological validity equal or superior to the data being gathered by current ground methods.

2) Makes it possible to gather data at a significantly lower cost and in less time.

3) Provides the resource manager with a type and form of data which is more acceptable by the general public than current data gathering and presentation techniques and forms.

4) Provides the resource manager with new tools to aid in the perception of complex resource issues.

NATURAL RESOURCE APPLICATIONS OF REMOTE SENSING

Land Inventories

In the late 1960s and early 1970s, the application of remote sensing to natural resources management became rather innovative and went beyond the traditional photo interpretation used by soil survey and timber management specialists. For example, Cosgriffe *et al*. (197) conducted a pilot study on 900,000 acres of the Decker-Birney area in southeastern Montana. Using color infrared (CIR), 1:40,000 scale aerial photography, they were able to identify and map vegetation types, agricultural lands, erosion condition, surface water resources, porcelanite deposits, mineral extraction and exploration sites, and other land uses.

Two men completed the Decker-Birney survey at an acceptable level of accuracy in several months. This same type of survey would have normally required a six-man ground crew. The cost for the entire study was $.0063/acre, as compared with $.0310/acre for a similar on-the-ground study conducted in 1964.

A similar broad resource inventory was described by Batson and Elliott (1975). An inventory of the Bureau of Land Management's (BLM) Rosebud and Coalwood planning units (approximately 2,800 square miles in southeastern Montana) was conducted using 1:80,000 scale CIR photography. The features interpreted from the photographs were vegetation types, wildlife habitat, current and past land uses, erosion condition and susceptibility, surface hydrology, turbidity of surface waters, porcelanite deposits, and range condition.

Wildlife Habitat

The U.S. Fish and Wildlife Service has developed a Habitat Evaluation Procedure which relies on remote sensing techniques and field measurements to rate wildlife habitat for various species (Pettinger *et al*. 1978). Photographs of 1:60,000 and 1:24,000 scale were interpreted to rate habitat for key wildlife species in the vicinity of phosphate strip mines in southeastern Idaho. This study demonstrated that, in the absence of extensive ground-based inventories, photo interpretive measurements can provide a viable means of performing elk and sage grouse habitat analysis.

The U.S. Fish and Wildlife Service (1980) relied on aerial photography (1:24,000 scale CIR) to map and rate wildlife habitat on the 1,094,031-acre Charles M. Russell National Wildlife Refuge in Montana. The Habitat Evaluation Procedure in conjunction with remote sensing allowed for rapid assessment of a large management area at an acceptable cost.

Gilmer *et al*. (1980) conducted a study using Landsat[1] imagery to enumerate prairie wetlands in the glaciated prairie region of North Dakota. A two-phase sampling approach was used which consisted of first making a total census of wetlands using Landsat data, and then adjusting the Landsat results on the basis of samples derived from high-resolution aircraft photography (1:20,000). It was concluded that this method has general applicability for estimating habitat features not consistently detectable of Landsat imagery.

Howland (1980) mapped the wetland vegetation in an area of Vermont using CIR, conventional color, and black-and-white photographs. Photograph scales of 1:52,000 and 1:104,000 were compared to determine plant community characteristics of a variety of wetland communities. It was concluded that CIR film was superior to the other films tested for classifying and mapping wetland vegetation.

MacConnell and Niedzwiedz (1979) used 1:12,000 scale panchromatic aerial photographs to evaluate the effects of stream channelization and land use on fish and wildlife habitat along the White River in Vermont. Vegetation types, stream flow characteristics, and land uses adjacent to the stream were mapped and used to study the impact of channelization on small mammal populations and songbirds.

Vegetation

Remote sensing techniques have been used extensively to evaluate features of natural and agricultural plant communities. Natural plant communities are often mapped and classified for timber production and/or range resource analyses. Vegetation damage due to insects, air pollutants, or other inimical environmental factors is often studied with the aid of remote sensing.

Murtha (1972) published a guide to air photo interpretation of forest damage caused by insects, fungi, and abiotic factors. This publication addresses pathogenic factors and photo interpretative techniques, spectral reflectance, and the relationship of films and filters to spectral reflectance.

Vegetation damage by oxidant air pollution was studied in southern California by Wert (1969). Approximately 100,000 acres of ponderosa and Jeffrey pine was evaluated using color photography (1:8,000 to 1:15,840 scale) to estimate tree damage and economic impact. The survey found that approximately 25 percent of the trees were damaged. The study costs were calculated to be $.03/acre.

Harney *et al*. (1973) used 35-mm, large-scale CIR photography to identify and delineate air pollution damage to vegetation near a coal-fired power plant. CIR film had good haze-penetrating qualities and was helpful in discriminating tree species that were stressed.

Driscoll and Coleman (1974) used large-scale (1:800 to 1:1,500), 70-mm CIR and color photographs to identify shrubs such as rabbitbrush, big sagebrush, mountain mahogany, and shrubby cinquefoil. They found that: identification of shrubs was more accurate with CIR than color photography; identification of

---

Landsat imagery is acquired by the Landsat series of earth-orbiting satellites.

some shrubs was easier regardless of film type due primarily to shrub size and species diversity; and identification of some species, such as snowberry and rabbitbrush, were difficult regardless of film type, season of photography, or photoscale.

In a study of short grass prairie vegetation of eastern Colorado, Shaver and Fisser (1973) used black-and-white, color, and CIR photography to delineate vegetation types. They found that a scale of 1:5,800 provided the optimum photo resolution with an adequate degree of precision.

Olson-Elliott and Associates (1981) mapped 14 native plant communities in Rosebud County, Montana, using 1:24,000 scale CIR photography. The mapping exercise allowed for the selection of representative community types for more detailed field studies.

Range sites in south Texas were identified using CIR and black-and-white aerial photography (1:19,000 and 1:42,000 scale) (Everitt *et al*. 1980). Film optical density measurements were used to separate eight grassland, two brushland, and two barren land range sites. The results of this study indicated that the potential is good for using 70-mm, aerial CIR photography in the summer to identify and inventory range sites on large, inaccessible tracts of lands.

Soils

Kolm (1975) utilized 1:24,000 scale photography and Skylab color photography (1:936,000 scale) to map soils high in selenium in Campbell County, Wyoming. The seleniferous shingle soil series and sandstone outcrops and the distribution of the selenium indicator species, *Astragalus bisulcatus*, was mapped on a county-wide basis. Density analysis and photographic enlargement were the primary methods used to interpret the photographs.

Torgerson and Hanson (no date) conducted studies on the Highwood Bench near Fort Benton, Montana, to determine whether soil salinity could be detected photogrammetrically. Their preliminary data showed that, using large-scale, black-and-white infrared film, soil salinity was correlated with the transmission density of the photographs.

Ecological Consulting Service (1974) conducted a research project to evaluate the application of CIR photography for the detection of saline seeps on the Highwood Bench near Fort Benton, Montana. Photography of two scales, 1:24,000 and 1:80,000, was interpreted to classify different sizes and types of saline seeps. The 1:24,000 scale allowed for a more detailed delineation of saline seeps and a more accurate classification of the seep type (90 percent accuracy). The 1:80,000 scale was approximately 55 percent accurate.

In a similar saline soil detection study, Rust and Gerbig (1974) photo-interpreted CIR photographs (1:40,000 and 1:10,000 scale) of an area of the Red River Valley in Minnesota. They found that elevated levels of soil salinity caused a reduction in the growth of cereal grains. Reductions in vegetation growth were apparent on the aerial photographs but on fallow fields salinity could not be mapped accurately. They determined that 1:40,000 scale photography was adequate for broad-scale mapping efforts, but that 1:10,000 scale photographs were more useful in locating relatively small saline areas.

CIR photography (1:10,560 scale) and thermal infrared imagery were used to map saline seeps in southwestern North Dakota (Dalsted et al. 1979). Results of this study indicated that an experienced photo interpreter can identify and map saline seeps accurately with a minimum of field checking. Thermal imagery provided little improvement over CIR photography for detecting mature saline seeps. Incipient saline seeps were, however, located more satisfactorily with thermal imagery.

Sophisticated studies were conducted in South Dakota to determine whether remote sensing techniques could be used to inventory the soil moisture in croplands and rangelands (Werner and Schmer 1972). A broad range of spectral reflectance measurements were taken at various times throughout the growing season. By using various filter-film combinations, spring and summer soil moisture levels were monitored for agricultural crops. Regardless of the spectral bands measured, it was not shown that remote sensing techniques could be successfully applied to monitor field moisture levels of rangelands.

Soil erosion and catchment conditions were assessed in New Zealand using 70-mm photographs produced from a variety of filter-film combinations (Stephens et al. 1982). The authors concluded that:

> •Aerial photographic assessment of erosion and catchment condition is cheaper, faster, and more accurate than visual assessment on the ground. It also provides a permanent record for future reference.
>
> •Large-format panchromatic photography, due to its cheapness, is the best medium for rapid erosion assessment, by virtue of its adequate detection of bare ground's characteristically high reflectance.
>
> •Multispectral color composite prints are superior to other forms of photography used, as an aid in catchment condition assessment, e.g., detection of old, revegetated erosion scars, determination of pasture grasses' vigor, and assessment of relative soil moisture variations on vegetated and unvegetated sites alike.
>
> •Black-and-white films used for multispectral photography are more stable, and less exposure-critical, than color and color infrared films. They tolerate targets with markedly different reflectances. Yet targets which have subtle differences in reflectance can be given strong color contrasts in the course of color composite printing.

- Small-format multispectral photography is too expensive and time consuming for coverage of large tracts of countryside at the negative scales normally used for large format panchromatic photography. The user must choose between sample coverage by large-scale negatives or complete coverage by prints enlarged from small-scale negatives.

Water Resources

Features associated with surface water status and agricultural land use have been inventoried in southeastern Montana using CIR photography (Batson and Elliott 1975, Cosgriffe *et al*. 1973). Wells, windmills, springs, reservoirs, diversion dams, streams, and canals were distinguished on photographic scales of 1:24,000 and 1:80,000. Reservoirs were classified into five general turbidity classes based on their spectral reflectance characteristics.

The U.S. Forest Service (Rosgen, no date) used large-scale (1:500) CIR photography to measure suspended sediment levels along 100 miles of the West Fork of the Madison River, Montana. Regression analysis was used to correlate ground truth measurements of suspended sediments with photographic density. This correlation analysis made it possible to make reliable estimates of suspended sediment yields from aerial photographs where stream measurements were not obtained. The total cost of this project, including helicopter time, film, film processing, field data collection and analysis, and photo interpretation, was approximately $22/mile of stream.

REMOTE SENSING APPLICATIONS FOR VARIOUS PROJECTS

Before a resource manager becomes immersed in a remote sensing project, he or she should be aware of the major advantages and limitations of remote sensing (Colwell 1964, Heller 1978). The major advantages are:

1) Reliability
2) Favorable vantage point.
3) Minuteness of detail.
4) Completeness of cover.
5) Ease of interpretation.
6) Opportunity to extend limited ground observations.
7) Ease of measurement.
8) Opportunity for studying areas at any time of the year.
9) Rapidity of obtaining data.
10) Suitability for comparative studies.
11) Economy.

The major limitations are:

1) Imagery may become rapidly obsolete.
2) Imagery may record or emphasize the wrong features.
3) Remote sensing does not totally eliminate the need for field work.
4) Prolonged training of interpreters may be required for acceptable accuracy.

5) Remote sensing techniques have often been oversold without adequate information on margin of error or confidence limits.

If, after considering the general advantages and limitations of using remote sensing techniques, it is deemed appropriate to become immersed in a project which relies on remote sensing, then several decisions must be made. These decisions relate to:

1) The scale of imagery to acquire.
2) The type of film or other image-recording medium to acquire.
3) How or where to obtain appropriate imagery.

Scale of Imagery

The scale of imagery is the ratio between distance units on the ground and the distance units of the imagery. Image scale greatly influences the resolution of certain details and image clarity or sharpness. The choice of scale involves compromise between the desired level of ground detail resolution and the number of photographs or other image frames required to cover the area under consideration (Holst 1975). The optimum scale provides for resolution at an acceptable level of detail, but at the same time requires minimum photography numbers.

The selection of the proper scale may take some experimentation and experience in image interpretation. It is not always acceptable to generalize from one project to the next due to the fact that image quality varies considerably because of lens/filter combinations and contrast levels of subject matter. If there is some doubt as to which scale is most appropriate, select larger scales. Being able to clearly discern a given detail is better than not being able to see it at all. In addition, the optical devices used to view or interpret stereoscopic photographs influence, to some extent, the scale requirements. If, for example, a high-quality scanning stereoscope (e.g., Old-Delft scanning stereoscope) with variable magnification to 10X is available, smaller scale high-resolution photography yields an acceptable level of image interpretation.

Literature on image scale suitability for interpretation of vegetational features seems to show a trend. Studies from the 1960s and early 1970s usually relied on relatively large-scale photography (approximately 1:5,000 or larger), whereas more recent studies often rely on smaller scales. This is no doubt due to improvements in technology in optics, image recording, and image interpretation.

Becking (1959), in applying photogrammetry to timber management, found that scales of 1:8,000 or 1:12,000 were most suitable for intensive forest management. Where individual shrub or tree canopies must be discriminated, larger scales are required.

Driscoll and Coleman (1974) reported the photo scales of 1:800 or larger were required for identifying relatively low-growing shrubs in mixed stands, whereas scales of up to 1:2,400 were acceptable for accurate identification of taller shrubs with more distinct crowns. Low-growing vegetation in the California foothills was delineated on 1:2,000 scale color photographs (Joy et al. 1960). Vegetational features, such as density, species composition, and forage weight, were discernible and formed the basis for successful delineation of plant communities.

Delineation of more general vegetation features, such as range sites, shrub and steppe communities, and forest communities, can be accomplished with large scales. Joy et al. (1960) found that it was possible to detect differences in species composition but not in forage weight at a photo scale of 1:10,000.

Olson-Elliott and Associates (1981) accurately mapped prairie vegetation dominated by big sagebrush, silver sagebrush, greasewood, and ponderosa pine, and associated grass and forb species, with 1:24,000 scale CIR photography.

Batson and Elliott (1975) identified four grasslands communities, six shrub communities, and four tree communities in southeastern Montana using 1:80,000 CIR photography. Driscoll and Francis (1972) found that scales of 1:80,000 were satisfactory for mapping savannah-woodlands and steppe vegetation where ecotones between the vegetation units were distinct.

Image scales smaller than 1:100,000 are obtained from high-flying reconnaissance aircraft (U-2 and RB series) and earth-orbiting satellites (Skylab, ERTS, Landsat, Apollo). For broad-scale mapping of regional vegetation, landforms, and land use, high-altitude photographs or electronically transmitted and recorded images provide an excellent synoptic base of reference. Laboratories with extremely sophisticated electronic gadgetry and computer capability for extracting information from images make claims of data acquisition that seem scarcely credible (and may, in fact, not be) to a classical natural resource specialist.

Film Types

Black-and-White

Most applications of remote sensing depend on the recording of electromagnetic radiation on films with photosensitive emulsions. Black-and-white, color, CIR, and black-and-white infrared film will probably be the choices for most resource applications.

Panchromatic (black-and-white) film is sensitive to electromagnetic radiation in the visible portion of the spectrum (0.4 to 0.7 micron range). Because of chemical emulsion stability, cost, availability, sharpness of detail, and sensitivity range (the same as the human eye), panchromatic is a commonly used film.

Color

Color photography differs from panchromatic in that the photosensitive emulsion on the film records three color dimensions (hue, value, and chroma) rather than shades of gray. Myers and Allen (1968) point out that increased tonal contrasts of color photographs expand the potential of the human eye to discriminate between different features on the film. They also point out that the human eye can only distinguish between 100 to 300 black, gray, and white tones, whereas it can make accurate distinctions among approximately 200,000 colors.

For the identification of most vegetational features, color photographs are generally superior to panchromatic. This superiority is due to the fact that the total information content is greater on color than on panchromatic. Also, the realistic recording and rendition of colors close to the perception of the human eye allows for photo interpretation with less training.

Color Infrared

Various studies have shown that infrared photography is superior to other types of photography for resolving differences in vegetational features, landforms, soil types, present and past land uses, rock outcrops, wet areas, ephemeral and perennial streams, and turbidity in surface waters. This superiority is due to the selective sensitivity of the chemical emulsion on the infrared film. Regular photographic techniques use the visible spectrum of 400 to 700 nanometers as source of illumination, whereas infrared photography records radiation in the 700 to 900 nanometer range. The recording of the 700 to 900 nanometer range on color infrared film and its translation into a visible component is the basis for the usefulness of color infrared photography. It should not be confused with thermal scanning or thermography, which records infrared radiation of wave lengths longer than approximately 1,150 nanometers as heat patterns. Thermal recording requires electronic or non-photographic means of detection and is prohibitively expensive for use over large areas.

Infrared-sensitive film primarily records color gradations which are not visible or only partially visible to the human eye. One of the more obvious characteristics of infrared photographs is the strking color variation between plant communities and the shifts in color as plant communities become physiologically stressed due to moisture deprivation, insect infestation, air pollutants, or other adverse environmental factors. As healthy vegetation becomes stressed or progresses toward natural senescence, the photographic color rendition shifts from various shades of red into magenta, purple, green, and brown as infrared reflectance becomes attenuated. This shift in reflectance has been attributed to several anatomical features of the leaf. Gausman (1974) found that leaf reflectance of infrared light is dependent mainly on the nature of the cell/wall airspace interface of the chlorophyll-containing spongy mesophyll cells and, to a lesser extent, on the cytological features of other tissues within the leaf.

Although CIR photography has some advantages over color and panchromatic film for detecting various vegetational features, there is evidence that the increased cost of CIR, its chemical instability, and its critical exposure characteristics make it unattractive for some applictions. Additionally, some researchers have found that visible reflectance from stressed vegetation is detectable on conventional color as well as CIR photography (Ciesla *et al*. 1967). Benson and Sims (1967) reported that conventional color film recorded insect or disease damage to forest trees as well as did CIR. They believed that the use of CIR introduced an extra "interpretational" step because interpreters were required to determine the significance of colors on the film, which differed considerably from the colors perceived by the human eye.

Black-and-White Infrared

Infrared black-and-white film is sensitive to electromagnetic radiation between 360 and 900 nanometers. Ultraviolet and visible light must be screened out by special filters to obtain total infrared effects. This film may have superior haze penetration features and be superior to panchromatic film for detecting vegetational stress.

Summary

Table 1 compares advantages and disadvantages of the different film types (Curtis 1973, Stephens 1976, Heller 1978). The choice of film types must involve compromises between advantages and disadvantages.

TABLE 1.--SUMMARY OF FILM CHARACTERISTICS

Film	Disadvantages	Advantages
Panchromatic	1) Limited tonal range	1) Sharp definition 2) Good contrast 3) Good exposure latitude 4) Inexpensive
Black-and-white infrared	1) Limited tonal range 2) Very high contrast 3) Slight resolution fall-off (without correction for focal distance) 4) Difficult to determine correct exposure 5) Loss of shadow detail	1) Vegetation evident 2) Tracing of watercourses facilitated 3) Inexpensive
Color	1) Expensive 2) Special processing facilities necessary 3) Diffusion of image under high magnification and slightly less definition than panchromatic	1) Excellent all-round interpretation properties due to good contrast and great tonal range 2) Good exposure latitude when used as a negative film 3) Good quality black-and-white prints can be produced from negatives
Color infrared	1) Expensive 2) Special processing facilities necessary 3) Diffusion of image under high magnification 4) Critical exposure 5) Low ASA rating 6) Less tonal range than color 7) Expensive and difficult to duplicate from positive film 8) Interpreter must translate the false color rendition of vegetation, soils, and other land cover features	1) Sharp resolution 2) Superior rendering of live and dead vegetation, faults, lineations, eroded surfaces, vegetation damage due to certain pathogenic agents and suspended sediments in surface waters

ACQUISITION OF IMAGERY

When the decision has been made that remote sensing techniques are applicable and desirable for a given project, choices must be made as to how the necessary imagery will be obtained. Three options exist for obtaining imagery:

1) Obtain already existing imagery.
2) Contract for new imagery.
3) Generate the new imagery in-house.

Existing Imagery

The choice of these options is dependent on time/cost factors and in-house capability or expertise. If one chooses to use existing imagery, it can be obtained from several places. The EROS Data Center in Sioux Falls, South Dakota, can provide many scales and types of imagery for almost all the regions of the United States. The EROS Data Center provides computerized printouts of the types of imagery that exist for a given area and can rapidly provide the desired product.

The U.S. Geological Survey has excellent data storage and retrieval systems for aerial imagery and maps. The National Cartographic Information Center at Reston, Virginia, acts as a national clearinghouse for available and planned aerial photography. Other sources of U.S. Geological Survey materials are: NSTL Station, Bay St. Louis, Mississippi; Rocky Mountain Mapping Center, Denver, Colorado; and Western Mapping Center, Menlo Park, California.

The U.S. Department of Agriculture maintains a center in Salt Lake City, Utah, which catalogues and provides imagery taken throughout the United States. Imagery collected by the various branches of the U.S. Department of Agriculture (e.g., U.S. Forest Service, Soil Conservation Service, Agricultural Stabilization and Conservation Service) and their contractors/consultants is also available.

If one plans to obtain existing imagery from any of the previously mentioned sources, sufficient time must be allowed at the beginning of the project. It may take several months to obtain the desired materials.

Contracted Imagery

New imagery can be acquired by contracting with private firms which specialize in aerial photography or other image production. Contracts are routinely let to private firms by Federal agencies. A good source of remote sensing contractors is the Journal of Photogrammetry and Remote Sensing.

When contracting with private firms, detailed specifications must be included which address optical standards, film types, photo quality, and other details. Requests for Proposals (RFPs) prepared by the Bureau of Land Management or

U.S. Forest Service are usually comprehensive and insure the desired product is obtained. Review of past RFPs or contracts should help one prepare specifications for contracting services.

In-House Acquisition

New imagery can also be obtained in-house, provided the necessary equipment is available or can be purchased. Woodcock (1976) described equipment and procedures for producing aerial photography with 35- and 70-mm cameras. Using a simple lightweight mount and minimally modified light aircraft, high quality aerial photographs were obtained.

The Bureau of Land Management (1974) field-tested application of a 35-mm aerial photography system for range management, watershed management, wildlife management, forest management, and mining/surface protection. The study team recommended that:

> 1. The BLM adopt the 35-mm Aerial Photography System as an alternative primary studies system for the range, watershed, and wildlife activities. Our field personnel are called upon to make many critical management decisions. The test shows that the 35-mm system gathers certain types of data more efficiently and meaningfully than our ground techniques do. We must not tie the hands of the field man. He must have the opportunity to use all available tools in order to do his job.
>
> 2. In support of the first recommendation, we urge adoption of the 35-mm system by all activities. As a tool capable of monitoring a variety of resource changes, the system has applications for nearly all activities including the following: forestry, recreation (including historical and archeological sites), minerals, surface protection, maintenance, and special problems such as saline seep.
>
> The 35-mm Aerial Photography System provides the BLM resource manager with an accurate, economical, and rapid tool to aid him in monitoring important changes on the National Resource Lands. This will improve our ability to make sound management decisions.

The use of 35- and 70-mm cameras with small aircraft has greatly expanded over the last 5 years. State agencies and private consultants routinely use this system when rapid assessment of relatively small land areas is required.

One of the most innovative systems for obtaining in-house remote sensing data has been developed and marketed by Electronic Devices Incorporated (EDI), a Great Falls, Montana, firm. By making use of a video cassette recorder (portable television camera with video tape) mounted in an aircraft, imagery of many scales and subjects can be rapidly and inexpensively acquired. The imagery can then be processed with an electronic device (LMS) which can density-slice and measure distances and areas. Various filters can be used on the video cassette recorder to measure different spectral reflectance bands which emanate from the earth's surface. A special camera is also available which detects and records thermal infrared images on video tape. Thermal imagery can also be processed with the LMS system. Once data have been collected on video tape and processed with the LMS, they can then be stored on a micro-computer system which is attached electronically.

This EDI system may offer applications of remote sensing to resource management that have yet to be discovered. Currently, State, Federal, and the private sector are using EDI's system to inexpensively and accurately perform many functions facilitated by the use of remote sensing and automated image processing. This system could be useful for in-house work at a nominal cost.

CONCLUSION

As with a number of scientific techniques, remote sensing has often been oversold and a method of assessing natural resources. People who are not familiar with remote sensing techniques often tend to believe that it has applications ranging far beyond the limits of technical and economic feasibility. Although remote sensing is an excellent tool, it should be considered only as an aid in resource evaluation and management; it cannot replace the need for experienced scientists such as range ecologists, wildlife biologists, and geologists with traditional on-the-ground skills. For any reliable interpretative effort, it is requisite that the interpreter be fairly knowledgeable about the particular resource being interpreted. For example, an interpreter of vegetational features should ideally be a plant ecologist familiar with the community structure of the area being interpreted. In addition, after the initial interpretation has been completed, "ground truth" checks must be carried out to determine levels of accuracy and source of error. Any successful interpretation must be coordinated with sufficient "ground truth" checks.

Heller (1978) stressed that all of us who work with remote sensing must guard against the "Gee Whiz" syndrome. This syndrome is best exemplified by the scientist who, upon seeing the first satellite photographs of the Mississippi River, exclaimed, "Gee whiz, that must be the Mississippi River." It was certainly the Mississippi River, but the real significance to the hydrologists was the fact that new oxbows and stream channels could be identified and used to update maps. Heller reflects that it is important that we use remote sensing to provide qualitative results which recognize errors and confidence limits. The true value of remote sensing lies not in the pretty pictures, but in the applications.

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SYSTEMS ANALYSIS AND ENVIRONMENTAL IMPACT STATEMENTS

by

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INTRODUCTION TO SYSTEMS ANALYSIS

The systems approach to any problem entails perceiving and resolving that problem using an a priori process. It is a method of analytically viewing the problem by involving inductive-synthetic-deductive logic to understand, organize, and project ideas scientifically (quantitatively) and, to some extent, qualitatively.

Two underlying principles govern the systems approach. The first principle is embodied in the concept of taxonomy, in which information is classified into a manageable system by gathering, grouping, and ranking. The second principle involves the concept of predictability. The information or data that have been gathered, classified, and ranked are organized so that their occurrence under given circumstances can be accurately projected into time and space.

The first principle is predicated upon systematically gathering reliable information. Information obtained randomly will need to be molded into a meaningful approximation of how the world actually works. This concept is cross-disciplinary, meaning that all disciplines must lend themselves to order and some relevance to taxonomy. Again, collecting information is meaningless unless this particular aspect of systems analysis is reinforced by a sound method of deductive or predictive methodology.

Prescribed Data Planning for Systems Approach

Inductive Reasoning	Deductive Reasoning
1. Relevant Information	1. Predictable
2. Categorized	2. Relevant
3. Ranked for Meaning	3. Ranked
4. De-Randomized	4. De-Randomized

(Inductive: Laws of Nature
Mathematics and Deductive
Logic (mechanics))

Once the information has gone through acceptable limits of reason and arrived at a rational level, it can be deduced that it falls within the bounds of probability and predictability. An example of this predictable methodology is demonstrated in Newton's second law of constant mass:

$$f = ma,$$

where, f = the force acting upon it,
m = mass, and
a = acceleration

(The change of motion is proportional to the motive force impressed and is made in the direction of the straight line in which that force is impressed.)

The concepts are relatively simple as expressed in Newton's second law of constant motion. However, each component of the equation must be grounded in empirical support, or the equation may lack relevance. In dealing with known variables, such as the mass of a given body, one can rely upon the information to obtain predictable answers. Again, this principle is applicable on a cross-disciplinary basis.

Many definitions of systems abound in the literature. In its very simplest form, a system is a mental process in which order is given to phenomena. It is an intellectual tool used to better understand both simple and complex things and events, and a method of drawing together interrelationships to form a holistic view. If applied and developed properly, a system will create a concept that is greater than the sum of its parts. It gives the perceiver a rational view of the world.

Webster defines a system as "a set or arrangement of things so related as to form a whole (a solar system, a school system); a set of facts, rules, etc., arranged to show a plan; a method or plan; an established, orderly way of doing something; the body, or a number of bodily organs, functioning as a unit" (Webster 1974). One of the more notable definitions is "a set of objects with a given set of relationships between the objects and their attributes" (Tilles 1963).

Stanford L. Optner elaborates on the definition of the systems approach and perhaps offers the best comprehensive definition of system by disagregating it into essential components. He outlines these parts as objects, attributes, and relationships. He further offers more formal definition of these terms:

> Objects are the parameters of systems; the parameters of systems are input, process, output, feedback-control, and a restriction. Each system parameter may take a variety of values to describe a system state.
>
> Attributes are the properties of object parameters. A property is the external manifestation of the way in which an object is known, observed or introduced in a process. Attributes characterize the parameters of systems, making possible the assignment of a value and a dimensional description. The attributes of objects may be altered as a result of system operation.
>
> Relationships are the bonds that link objects and attributes in the system process. Relationships are postulated among all system elements, among systems and subsystems, and between two or more subsystems. Relationships may be characterized as first order, when they are functionally necessary to each other. Symbiosis, a first-order example, is the necessary relationship of dissimiliar organisms; for example a plant and a parasite. Relationships may be characterized as second order if they are complementary, adding substantially to system performance when present, but not functionally essential. Synenergy is a second-order relationship.

> Synergistic relationships are those where the cooperative action of independent agencies taken together produce total effects greater than the sums of their effects taken independently. Relationships may be characterized as third order when they are either redundant or contradictory.
>
> Redundance describes a state whereby the system contains superfluous objects.
>
> Contradictory conditions exist when the system contains two objects which, if one is true, the other by definition is false (Optner 1965).

Systems and subsystems are methods of breaking the whole down into various parts not only for descriptive reasons, but for relevance of the parts to the whole. When the parts are fully functioning within the framework of the whole, a new dynamics will occur far greater than each part. An example of an easily perceived system is the automobile. When each subsystem or part is working in concert with the other subsystems, the whole transforms itself into a moving body constrained only by the systems design and viability of each subsystem.

Another way of perceiving a system is through mathematical expressions. Perhaps the most profound yet simple system analysis expressed in the 20th century is Einstein's theory of relativity, noted through the formula $E = mc^2$. Each part of the formula is essentially a subsystem and a complicated analysis unto itself. However, taken in the context of the formula and interrelated parts, a dynamics occurs. The subsystems, in which M = matter or mass multiplied by C = the speed of light, squared, ultimately produce the underpinning of man's understanding of the nature of the universe and also the nature of energy in the context of the universe.

In summary, what the systems analysis approach does for man is provide him with a methodology for classifying systems and subsystems, an orderly description of spatiotemporal events, and also a predictive method for deriving an approximated view of the future. The systems approach is as old as Aristotle's simple classification of the elements of nature and as complex as the most advanced computer retrieval-forecasting system used by Bell Telephone System and National Defense Networks. In the 20th century, it has become widely used with both benefits and failures, some of which will be elaborated on throughout this paper. The problem of perceiving the environment in a systems way is equally as complex and exacting.

Comparative Qualitative and Quantitative Analysis

Probably the most difficult aspect of the EIS process is to derive a cross-disciplinary approach that systematically details not only the existing environment but also the impacts superimposed by the proposed action or development. At the very root of this problem lie the baseline data in terms of quality and quantity for each discipline. Most disciplines can be measured quantitatively if the baseline studies are conducted with a methodology that fits impact analysis.

The most troublesome disciplines to successfully model are those that inherently lack sufficient data or are inherently subjective. In either case, the EIS author must rely upon professional judgment to arrive at a conclusion. In the case of insufficient data for a critical discipline such as hydrology for a mining operation, the author can either argue by analogy or demand that more information needs to be gathered to suit the needs of a hydrologic model (or both).

For disciplines that are subjective by nature, such as sociology, aesthetics, and to some extent, land use, the environmental researcher should use existing measuring techniques. In the area of sociology, longitudinal study methods are currently being used to historically analyze populations affected by Western coal development. This methodology opposes the quickly conducted and project-specific methods widely used in attitudinal studies. Attitudinal studies are still valuable, but only to the extent that they are designed to satisfy longitudinal study needs.

In the area of aesthetic impact evaluation certain accepted methodologies have been developed by the Bureau of Land Management (BLM) and the U.S. Forest Service (USFS). The BLM's system is somewhat arbitrary and not always applicable to all site-specific analyses. The USFS's system has the same shortcomings. However, both possess a systems approach to subjective and qualitative environmental problems.

Costs and Benefits of the Systems Approach

Since the passage of the National Environmental Protection Act (NEPA) in 1969, people, governments, and corporations have been looking for ways to streamline the environmental impact statement process. The requirements of the law are very demanding but general at the same time. In attempting to make the law viable in dealing with a multitude of environmental changes, a systems approach is vitally important.

One of the earlist approaches to environmental impact statements was to use a matrix to understand the various subsystems within the environment and their relationships. The major benefit in this approach was the researcher's ability to define as many subsystems as possible in a given system. The major problem was the complexity and the difficulty in obtaining sufficient data to accurately construct a model depicting the future. In many cases the matrices contained information superfluous to the action that was being proposed. However, matrix models can help us understand the existing environment and the fundamental relationships.

A difficult problem with modelling or a systems approach is that the data become systems bound. Each system has its own constraints. The systems analyst must recognize that limits exist with all models, especially those that are not time-tested. The analyst should approach each model with an eye for those constraints and duly compensate for them. A case in point would be to carefully respect an environmental impact used in the discipline of hydrology when sufficient data aren't available to give the model outputs reliability within reasonable confidence bounds.

Another consideration is the evaluation and use of assumptions in systems analysis. All systems are based on certain assumptions that govern any analysis. All assumptions should be carefully weighed to determine their applicability and reliability.

The net effect is that the benefits certainly outweigh the costs of a systems approach to environmental impact analysis. However, as mentioned, assumptions and constraints used in an analysis must be made clear. The researcher can then proceed with some assurance of reliability and accuracy. Without a systems approach the EIS process would lack order and scientific meaning.

Graphic Illustration of Systems Analysis Approach

When the environmental impact analysis process is subjected to a systems approach, it can be reduced from words to submodel diagrams, and in some cases to computerized formating. Probably the best example of illustrating a systems approach is a conceptualized economic demographic modeling process.

As stated earlier, each model is derived from various submodels, constraints, and assumptions. Once the basic parameters are defined, conceptualized, and verified, the model can be made operational. This can be done either manually, or, if too complex, by computer.

An operationalized economic demographic model (E/D model) is predicated on certain assumptions and historical parameters that have been empirically proven. Since the model will provide a spatial-temporal picture of the subject studied, it can be depicted on a time/production graph (Fig. 1). The X axis depicts time, and the Y axis depicts labor employed by a new project or proposed action.

Basic employment is shown in the shaded area. Secondary employment is depicted by the dotted zone. Total employment is what falls under the curve S. Employment (T) is a function of basic employment plus secondary employment:

$$T = S + B + I \text{ (Indigenous Employment).}$$

Figure 1 shows the relationships between T and time. However, the proposed action, or new development, is shown by B + I curves in the context of history and the future. The parameters in the diagram can be used to develop economic information associated with each worker and the total population. Again,

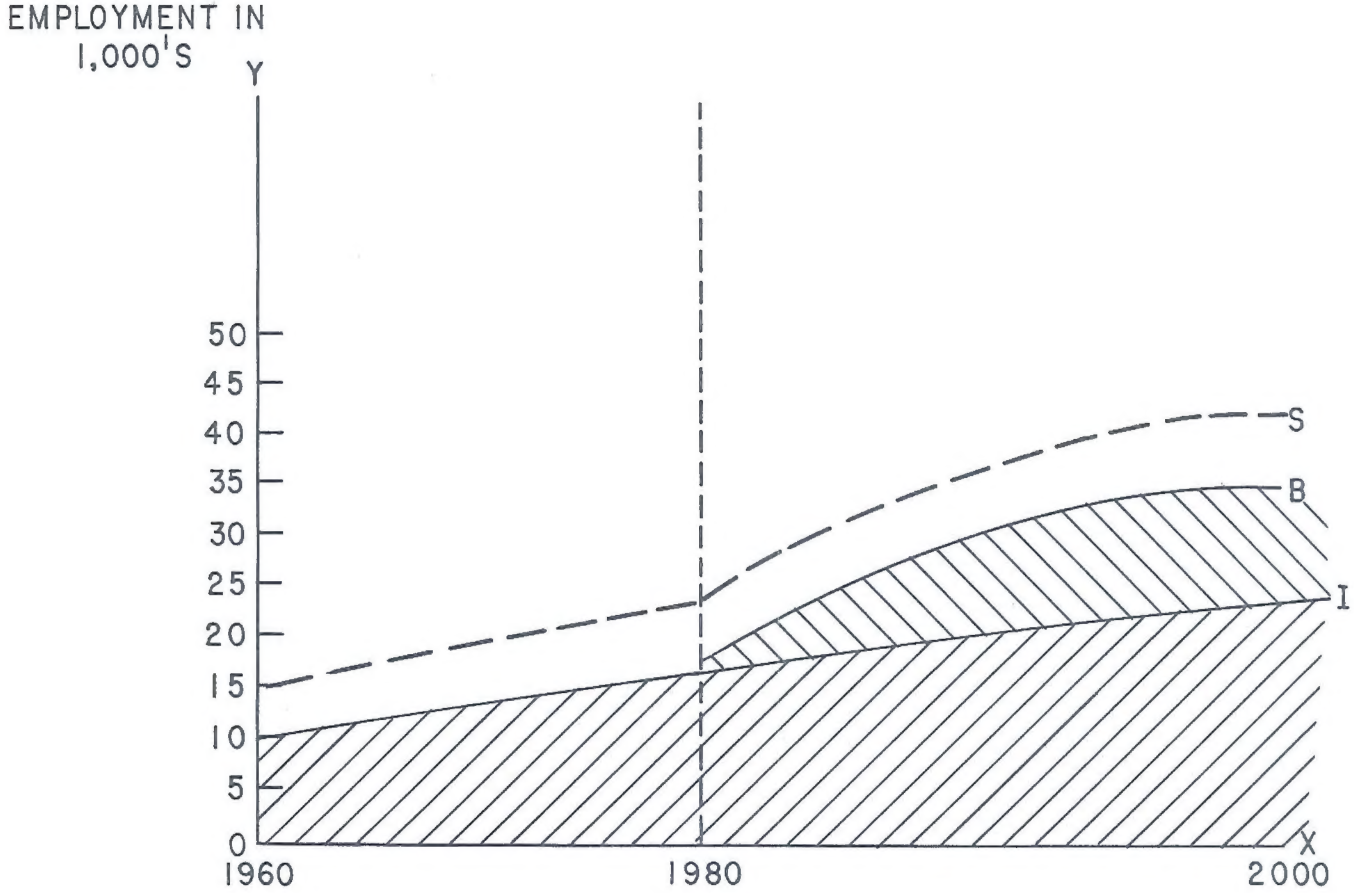

FIGURE I EMPLOYMENT POPULATION CHANGES RESULTING FROM PROPOSED ACTION

caution should be taken in that applicable multipliers would be attached to both basic and secondary workers to derive total population. A constraint would be that the type of development, should it be a factory worker, coal miner, or government employee, would have a specific multiplier attached to each parameter that is site-specific and not necessarily universally applicable.

To derive total population (demographics), a series of submodels would have to interact to produce total population and economic analyses, at any given point along the X axis. Figure 2 illustrates the interaction of the submodular parts.

The researcher should be aware that the model outputs are based on assumptions and, more importantly, that because population figures are predicted, subjective issues such as quality of life concerns in the future may not be derived from the model. The model simply offers an approximation of the numbers of people employed, specified economic data, and the derived total population in a given area during a given time.

SYSTEMS ANALYSIS AND ENVIRONMENTAL BASELINE STUDIES

Data management is the largest difficulty in assessing all the dicsiplines for writing an EIS. Writing an EIS should be a continuum of spatial-temporal underpinnings. Collecting the data or baseline information should be conceived as a triadic process, it should be integral to its history, present, and future. All parts of the process should interlink. Figure 3 illustrates how the researcher should perceive the baseline as part of a dynamic whole.

Management of data in the EIS process is the key to successful and legal impact assessment. This management of data is also clearly a systems analysis problem unto itself. Each aspect of the process must stand alone and yet interact dynamically with the other model components.

The data for each discipline will vary in a cross-disciplinary fashion in terms of quantity and quality, however, the total baseline must be dynamic and interactive to meet the needs of the second component, or the existing environment. The existing environment is a function of and is derived from the baseline data. The baseline data are derived from several sources: legal mandates in NEPA, Federal and State regulations, and from empirical studies. The baseline can be tailored, or it can be gathered in an isolated fashion having little or no relevance to the other model components in the data management process. To collect data in a haphazard manner can be costly and ultimately the entire EIS process will fail.

When all components are functioning in concert with each other, a dynamic view of the past-present-future environments can be readily depicted. Figure 4 shows the relationship in which a truly successful data arrangement system can be obtained.

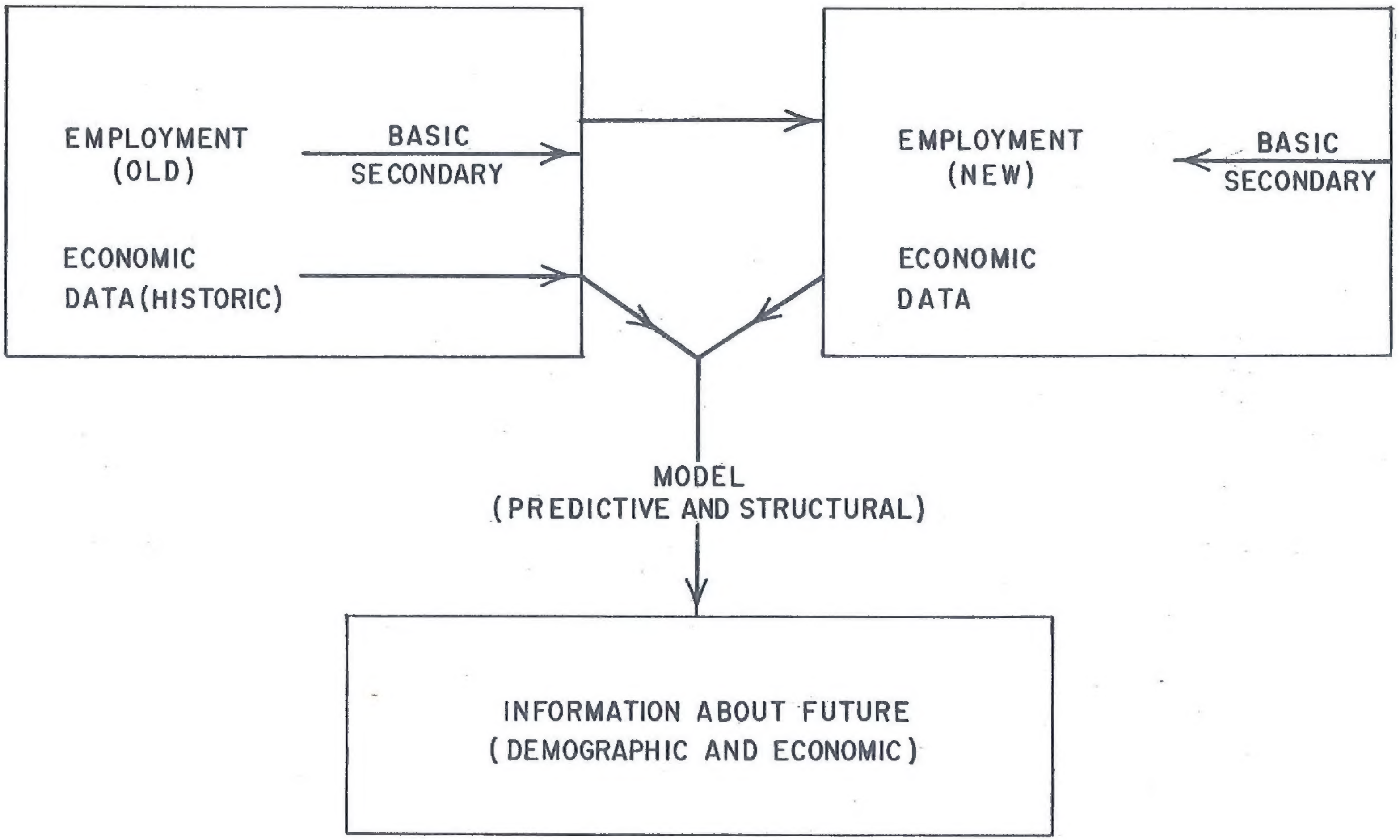

FIGURE 2 SYNTHESIS OF HISTORICAL AND PROPOSED ACTION DATA TO FORM FUTURE ANALYSIS

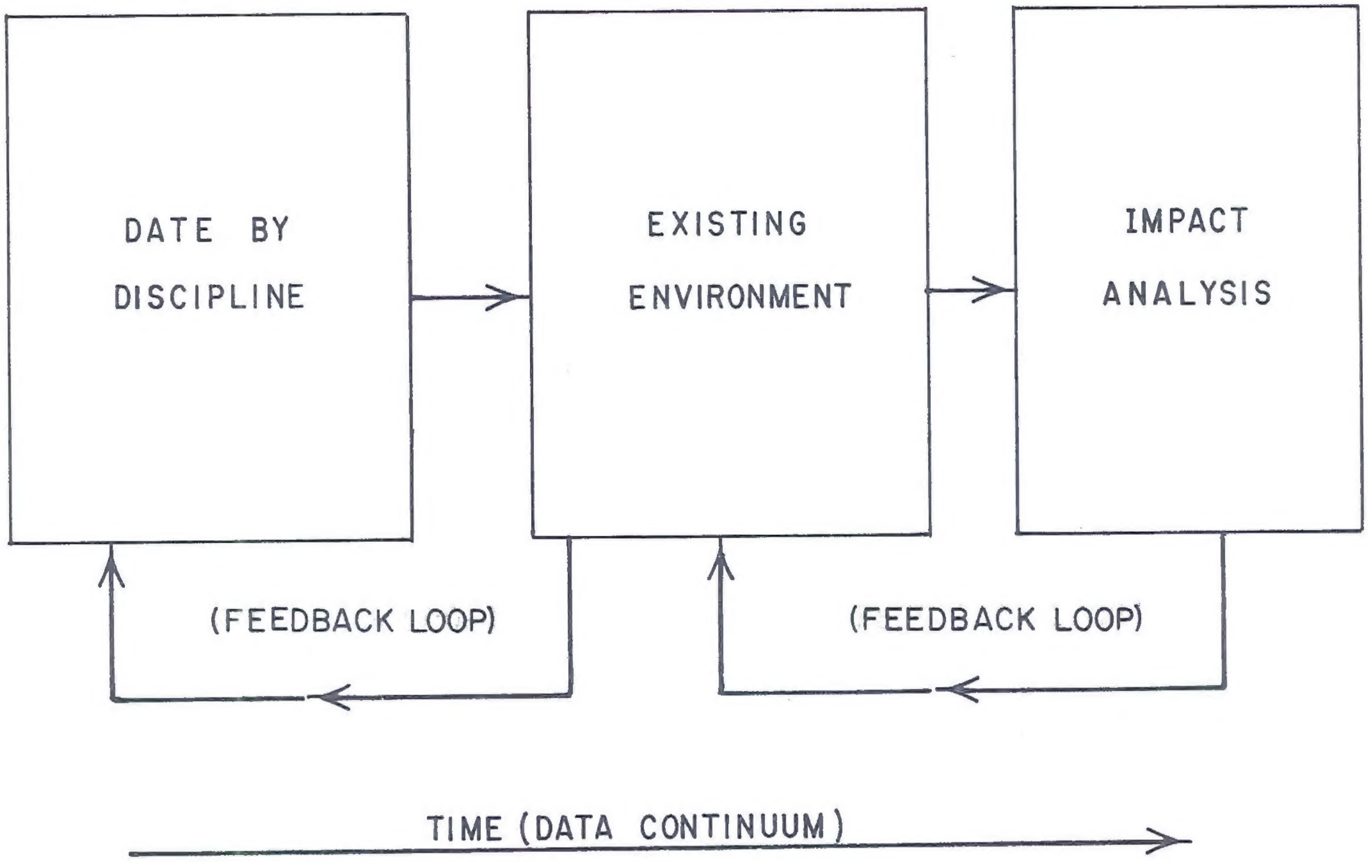

FIGURE 3 DYAMIC PROCESS FOR ANALYZING EXISTING AND FUTURE ENVIRONMENTS

Data design is central to the success of the total impact analysis. The researcher, when planning an EIS document, carefully evaluates all data available in his or her discipline. Public hearings will reveal which subjects are of particular concern; previous work done in a specific discipline can be obtained through a library literature search, through other government agencies, and through professional and industry journals.

Once the major issues are discerned, all information must be compiled for all disciplines. The researcher must then determine if adequate data exist to analyze the existing environment. In many cases, new information must be gathered. The scope of the document will begin to evolve and take form. The data, in this preliminary form, are most subject to manipulation to form a sound methodology upon which longitudinal studies can be conducted. The longitudinal approach will alleviate the problems of necessitating new studies for permitting reasons or a major change in the proposed development at some later point in time. A strong study base should be established through the longitudinal approach.

Data language and applicability to systems analysis are primary factors when dealing with similar disciplines, particularly when more than one proposed development is to be studied in a regional or sub-regional context. Even if data are collected over a long period, it is essential that they be kept in one computer language, or in a systematic retrieval system. Without a common language and accurate records, no systematic method exists to evaluate impact analysis. Again, this basic premise will determine the scope, the cost, and the time required for preparation of the document.

In many cases when an entire environmental system such as hydrology is assessed, the data must first be gathered and put into a compatible code for a certain computer before they can be successfully analyzed. This is particularly true when examining large systems that require the assimilation and processing of literally millions of data points.

Data gaps are the most glaring flaw in any analysis, particularly when studying a new area. When data are missing, it is appropriate to estimate or argue by analogy, or by extrapolation. This technique is commonly used in the impact statement process; however, special caution must be taken to ensure that an adequate sample size exists, and that the argument is valid to a particular situation. If the information is scant, new primary information should be gathered when critical concerns are being examined. Necessary information to fill data gaps should also be gathered to satisfy the desired longitudinal design of environmental work.

SYSTEMS ANALYSIS AND ANALYTICAL FUTUROLOGY

Futurology is a subject of great interest and has been for many centuries, from the very earliest fortune tellers to the most sophisticated predictive computers analyzing international war games. As Victor C. Firkiss states, "Man is intoxicated with the future," and tends to shape the present through the prison of an imaginary future (Firkiss 1969). More importantly, since the end of World War II, man has become obsessed with forecasting not only accelerating world populations, but also energy consumption trends and world-wide resource shortages. These forecasts are exemplified in literature produced by The Club of Rome, Herman Kahn, Anthony F. Wiener, F. Jungk, and F. Galtung, to mention a few prominent futurologists.

Once the methodology and techniques necessary to produce mass predictions for large-scale planning became available, companies large and small began their own predictions on demand and supply for given commodities, such as electricity and the use of steel. Most of this forecasting in the late 1960's and early 1970's involved linear projections based on historical trends. The methodologies were sound given certain assumptions; however, the essential feedback loops did not exist, and corporate America began building for a future based on trend projections. A trend analysis is no more than a projection based on historical data. However, the critical feedback loops denoting radical price changes, conservation, and substitutability were lacking. The projections simply became an historically determined "present" in which today's growth was geared toward tomorrow's prediction. Today's growth rate in almost all areas has been revised downward to adjust for the feedback loops, such as recessions and radical swings in inflation. By reducing future predictions designed to fulfill self-interest forecasts, the present is adjusted to meet the realities of today and tomorrow.

The futurology that the EIS researchers utilize is more site-specific than that of Charles Reich's The Greening of America or Walt Rostow's Stages of Economic Development. However, the concepts used were and are a continuum of the futures games on a micro-scale. At times, more expansive futures analyses are used to make supply and demand assumptions. Some of these sources are energy forecasts by the U.S. Department of Energy, and commercial sources such as Chase Econometric Forecasting. These macro-predictions should be used with some reservation and caution, particularly the energy forecasts, which suffer from the same trend line prediction problems of earlier forecasts.

Theoretical Approaches to Systems Analysis and Futurology

The EIS researcher should conceptualize problems using some simple theoretical and analytical tools. The first step is to understand what the problem constitutes in terms of spatial-temporal analysis. This can be accomplished by developing a compartmentalized, multidisciplinary time and space graph looking at the past (baseline) and present (existing environment). Figure 4 shows a methodology that can be used to study the existing environment to help determine future environments.

With the environment properly conceptualized, the model can be theorized to determine interactions and produce a truly cross-disciplinary analysis with the consequences of the proposed action interacting dynamically.

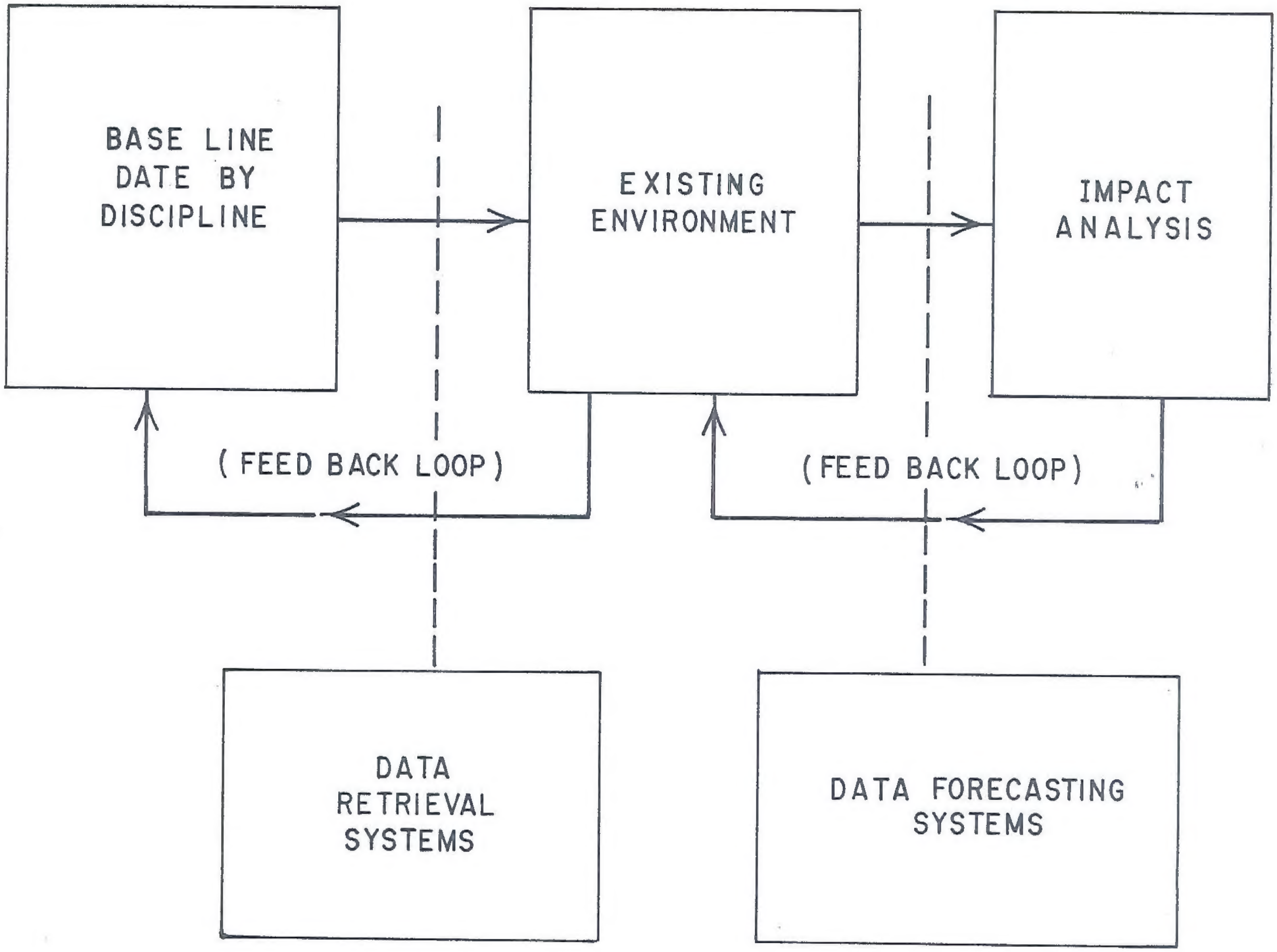

FIGURE 4 INTEGRATED ENVIRONMENTAL IMPACT STATEMENT ANALYSIS

Development of Floating Baseline in Analytical and Graphic Form

One of the most important concepts for the EIS researcher to recognize is the concept of the floating baseline. The floating baseline is the changes in the existing environment that would occur without the proposed action. It is a matter of looking into the future in a given study area and determining what other forms of development can be expected to increase or decrease. It is essential to futures analysis, because it will determine what net changes can be anticipated in relation to the proposed action.

In rural communities, where agriculture has historically been the primary industry, population can have a net decline over time. Agriculture has become more capital-intensive over time, with a net decrease in labor required to obtain constant and in some cases increased agricultural productivity. For example, let's look at a rural community in Montana in which agriculture-related population has declined over the last 30 years (Fig. 5). If a coal mine were to be developed here, the researcher should differentiate the increase in the mine employment, secondary employment, and agricultural population declines. Figure 6 illustrates the hypothetical net difference between energy growth and agricultural decline in population.

To determine the floating baseline for futures analysis, the researcher must account for historical trends in base populations in all sectors, and also all proposed development in a study area. This can be accomplished by reviewing past and current development and by gaining a working knowledge of development proposed for the future. If the researcher wishes to obtain a proposed site-specific analysis in the context of cumulative development, all future development must be acknowledged, within the realm of reason. The best way is to contact all government and corporate agencies interested in future development in a given area. Once a list of future development is established, employment and production data can be projected. Figure 7 demonstrates how the floating baseline can be derived to show future production in a given area. Production of coal can be used to illustrate the floating baseline; population and other pollution indicators can also be used.

To expand the floating baseline concept, the researcher must incorporate all development, not just Mine A, but all mining, including other mines and industrial development. For simplification purposes, only two other mines (B and C) and one coal-fired generator will be analyzed. Figure 8 draws in mines A, B, and C to illustrate cumulative future mining with each mine having a 20-year life. At the year 2000, maximum cumulative coal production is attained with mines B and C in operation. Mine A has reached the end of its mine life and no longer produces. After the year 2000, the existing mines go into a decline, and along with this decline, associated population and employment declines result. Population net impact would peak for the coal mines at the year 2000. However, total population impact would be influenced by other development, such as the coal-fired generator and net declines in agriculture population. The total impact would be the result of multiplier coefficients depending on the area. Figure 9 demonstrates how the population curve would react given the influence of the coal-fired generator and the cyclical nature of Mines A, B, and C.

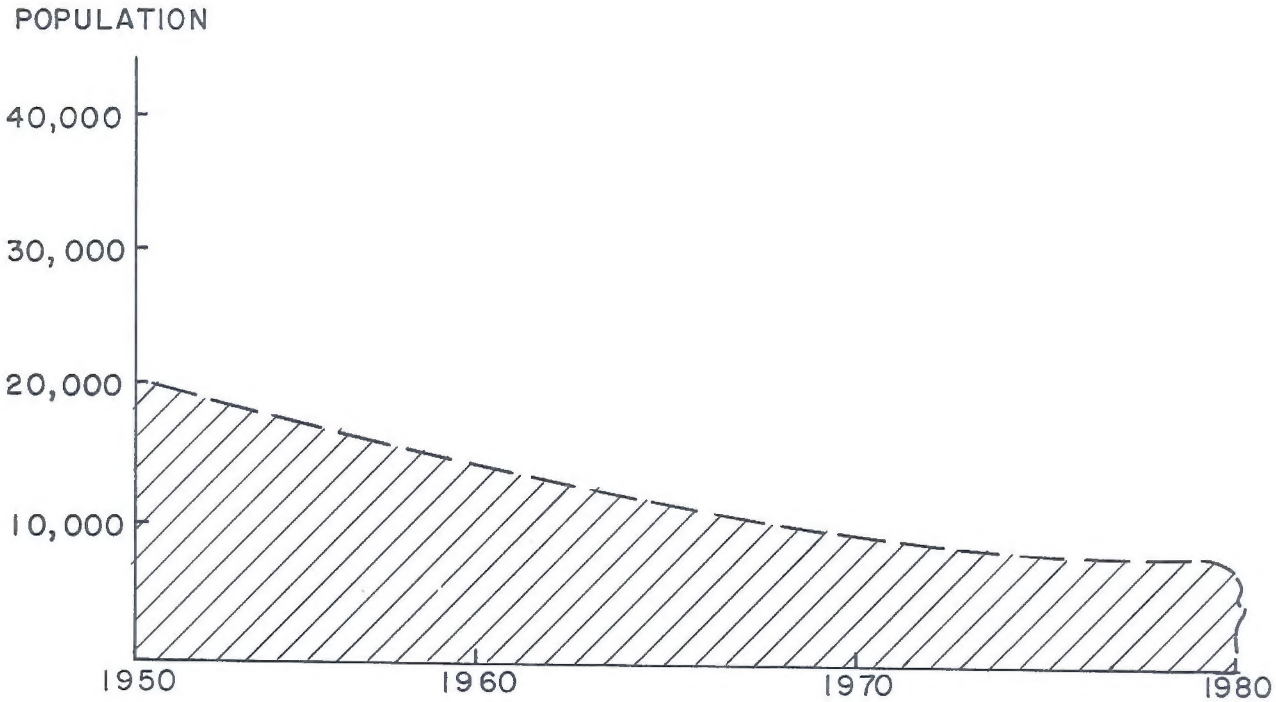

FIGURE 5 POPUATION IN RURAL MONTANA COUNTY WITHOUT COAL MINE (PAST, PRESENT)

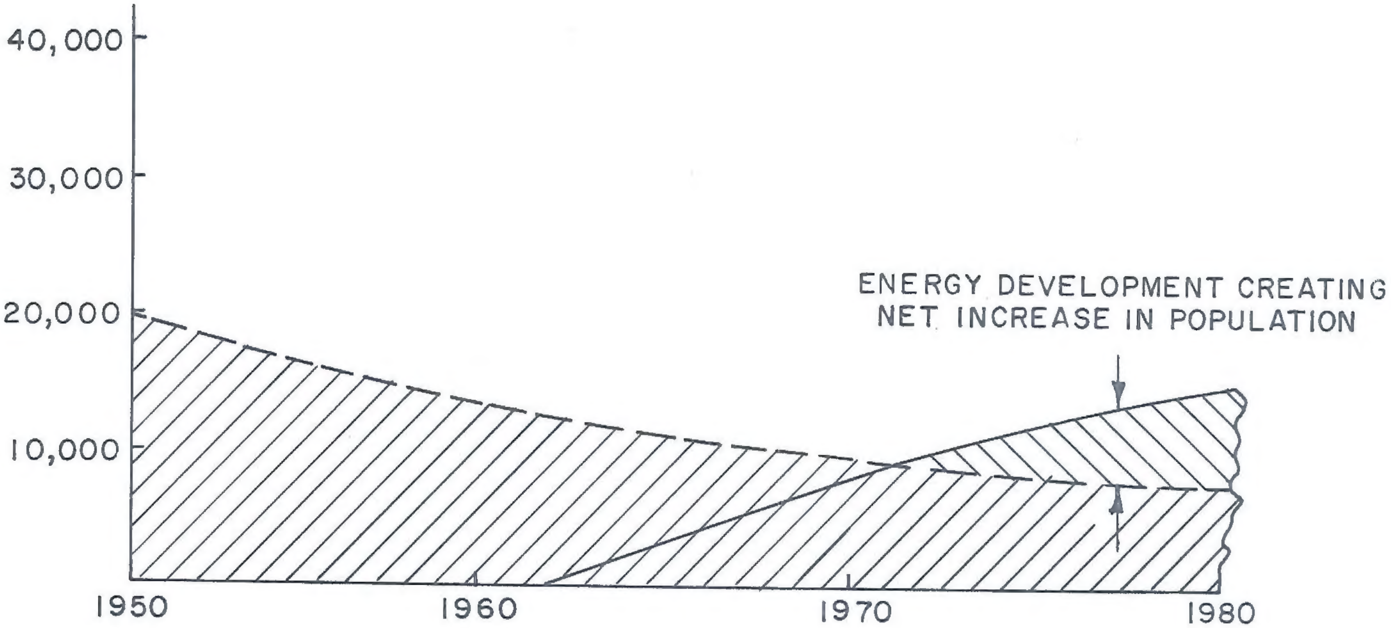

FIGURE 6 POPULATION IN RURAL COUNTY WITH COAL MINE

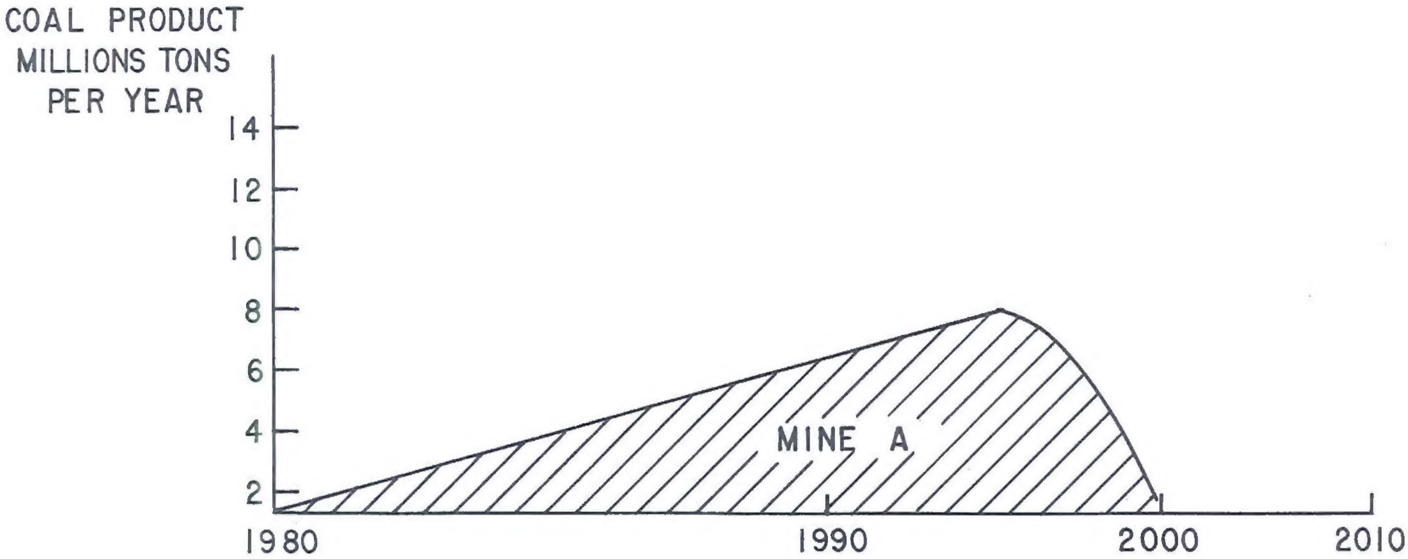

FIGURE 7 FLOATING BASELINE MODEL

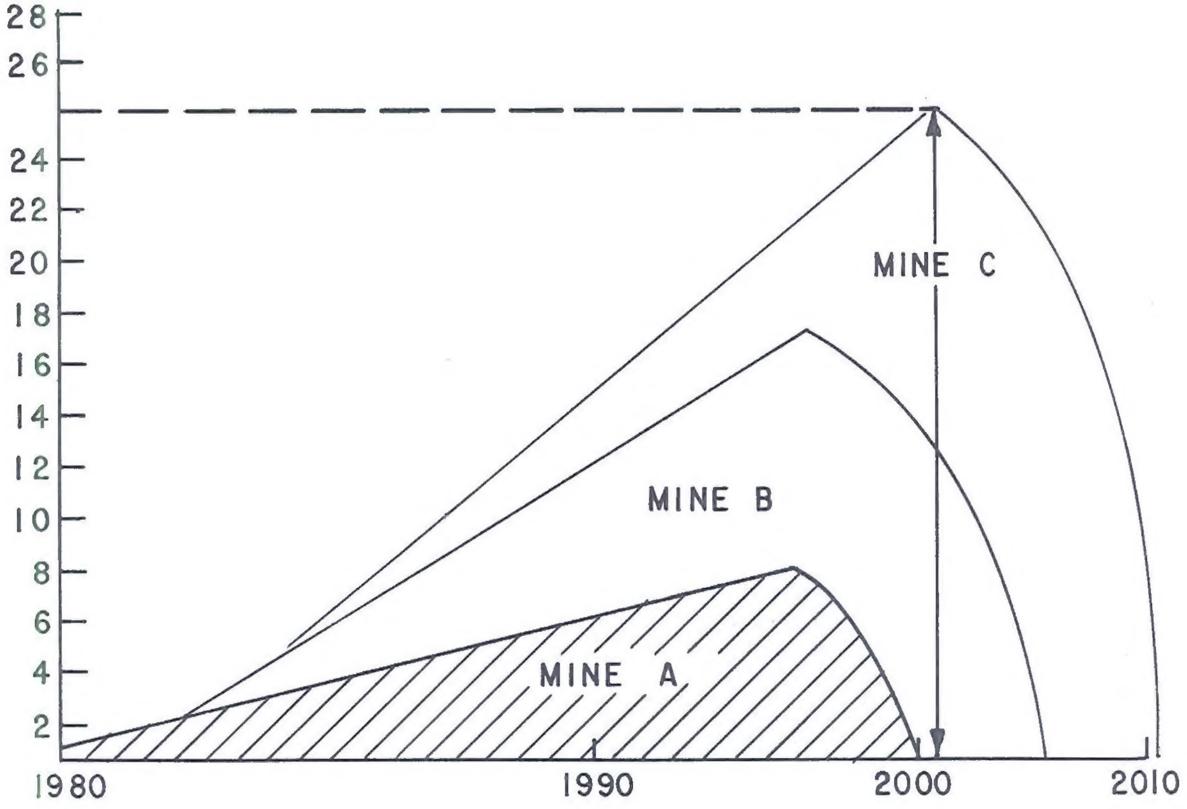

FIGURE 8 CUMULATIVE IMPACT FLOATING BASELINE MODEL

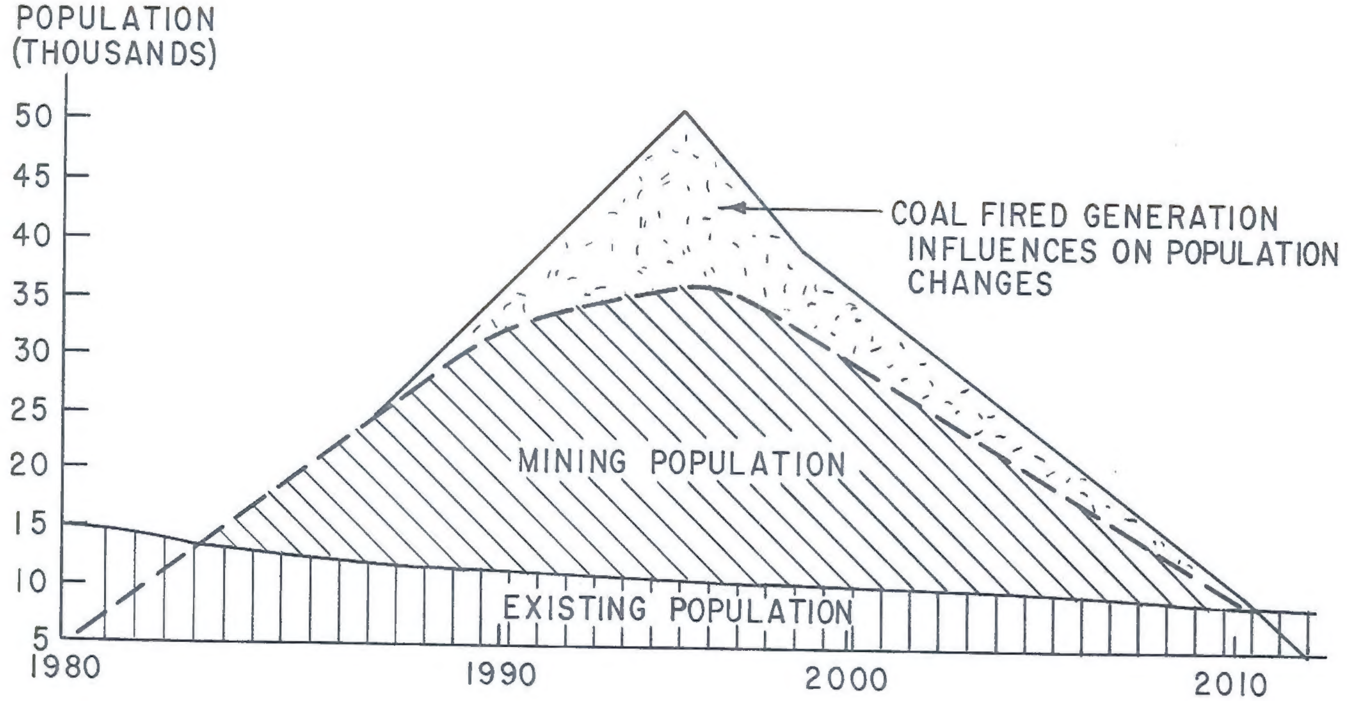

FIGURE 9 POPULATION COMPARSION

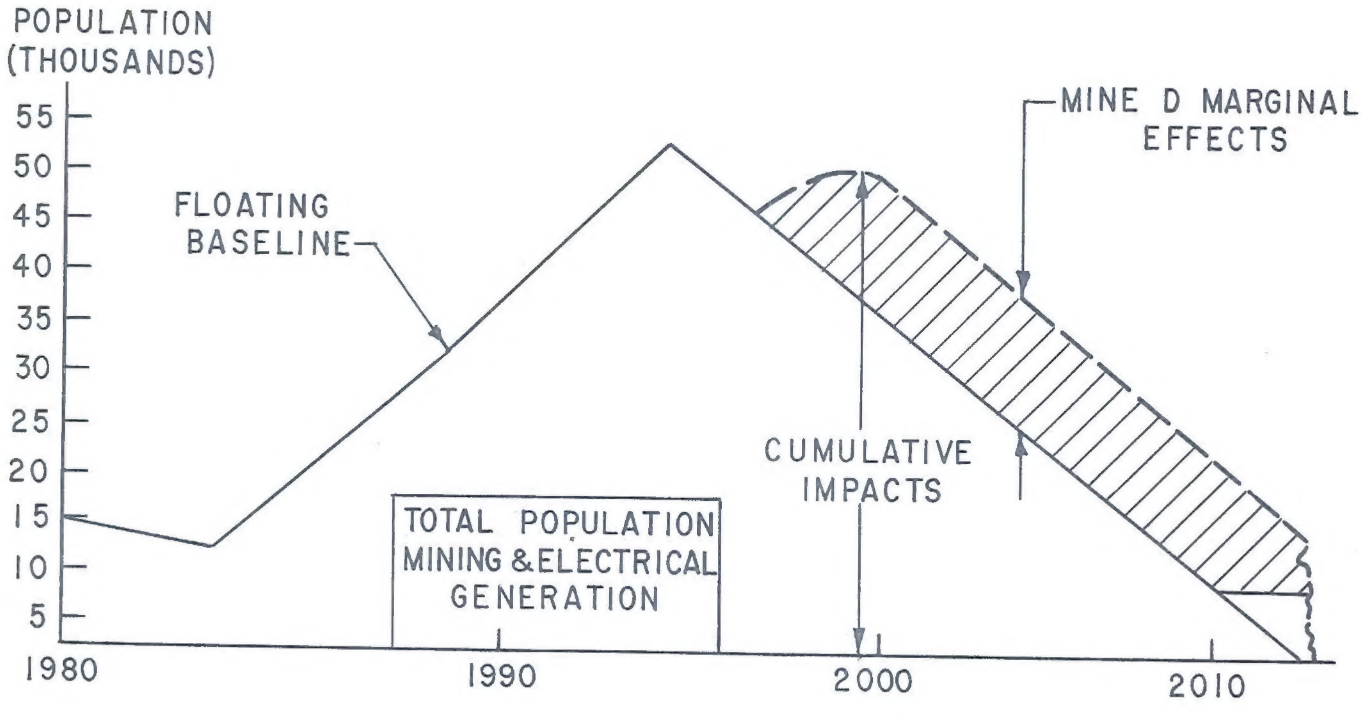

FIGURE 10 CUMULATIVE POPULATION EFFECTS

Total population impact would occur about 1995 when construction on the coal-fired generator reached its apex. Note that the net impact is an increase of about 30,000 people over the existing agricultural community.

The total increase and the known agricultural community illustrate what we know about the future in a dynamic graphic sense. The future baseline is not static and reacts to various forms of developmental influences in terms of total population and coal production.

Once the researcher understands the floating baseline concept, any number of new mines can be added to the analysis to obtain a working understanding of the marginal effects of new development. If a site-specific Mine D is added, both population and production can be ascertained. Figure 10 derives the total cumulative and the marginal addition of Mine D to the floating future baseline. This concept serves to help the researcher dynamically perceive the past and particularly the future. Analytically, it brings into focus all development in both a site-specific and regional context. Not only are net cumulative impacts realized but site-specific development can be ferreted out in all disciplines.

Limits to Systems Analysis and Futurology

As we have seen so far, the systems analysis approach to environmental impact analysis is a way of looking at the past, present, and future in a dynamic, cross-disciplinary perspective. However, it must be pointed out that systems analysis is only an approximation of reality. It is only as good as the data used in the analysis, and only as strong as the methodology used. Without reliable data and methodology, the systems approach is no better than alchemy and crystal balls. The researcher should strive to upgrade and refine data and to seek the best models available to perform a futures analysis.

INDUSTRIAL-ENVIRONMENTAL PLANNING WITH LEGAL CONSTRAINTS

State and National Environmental Policy Acts as Guidelines to the EIS Systems Analysis Process

Two major factors play a role in determining the quality of environmental impact statements. The first is timing and the second is budgetary. In most cases a specific time schedule is imposed on the document. This time constraint can be from local, State, and Federal regulation, or a combination of two, or all three. The time constraint is designed to ensure that documents are written so as not to delay the proposed action inordinately and to obtain an accurate perspective of the existing environment. Although the latter goal is significant for the analyst, to unjustly delay a proposed action is probably of greater importance. This is particularly true when large capital investments are involved, and in the case of metal mines, when the market cycles to high points.

The budgetary constraint is of prime importance in that sufficient funding should be provided to produce a professional document. Enough funding must exist to undertake collection of baseline information and preparation. In California, EISs are funded by local government agencies in many cases. In Montana, a user tax, or Montana Environmental Policy Act fee, is placed on the company proposing development or an action in the environment. If the Federal government is involved, the U.S. taxpayer assumes the cost of the environmental work and the impact statement itself.

Because the cost of producing EISs has risen dramatically over the last 10 years, it is of vital importance that environmental work be timely and cost-effective. In many cases, costs have increased fourfold to tenfold, even though guidelines for EIS preparation have been streamlined by the Council on Environmental Quality (CEQ). Some States have followed these Federal practices in terms of producing site-specific documents of no more than 150 pages, and major and complex documents of no more than 300 pages. These Federal guidelines also stipulate that regional and programmatic analyses be no greater than 300 pages. Technical reports can accompany the EIS itself, but routine technical reports should be kept on reserve by the lead government agency, and issued upon request (CEQ, 1978).

A systems approach is one of the most cost-effective methods of providing the decisionmaker, the public, and the government with legally required EISs. For an EIS to incorporate a systems approach, the basic methodology must be not only integrated to provide a basic analysis, but also longitudinal in scope--that is, a methodology that can be used and refined over time. Most EISs are historical period pieces in which the existing environment is the launching point. For future or impact analysis, caution should be taken to guarantee that the snapshot of the present environment is empirically proven, and that information used to formulate this depiction can be used in other EISs. The longitudinal systems approach offers a system that can be reused over time and built upon. It also helps to standardize the requirements for the baseline collection and the environmental impact statement itself.

The systems approach is more costly during the research and development periods. However, once it has been operationalized and verified, it can be refined to depict reality more accurately, and, more importantly, it can be used again. As the environment changes, the systems approach can be quickly adjusted to demonstrate changes in the existing and future environments. Most major projects not only change their plans to adapt to existing needs in the environment, but also to changes in the market. In some states, such as Montana, the large strip mining operations must apply for a permit renewal every 5 years. In most cases, their permit renewal requires either a new EIS or an addendum to the original EIS. If the original document is predicated upon a verifiable and longitudinal systems approach, an addendum can be prepared to the original document incorporating the changes in the developmental expansion. If the original document is prepared with no logical systems approach, a totally new document must be prepared.

Site-Specific and Regional Analyses

Generally, a systems approach to EIS preparation is more applicable to site-specific situations for most disciplines. Data normally become more diffuse and difficult to obtain on a regionwide basis. Site-specific models are available to depict disciplines such as hydrology, air quality, and economics/demographics.

If the researcher is confronted with regional analysis, it is suggested that site-specific modeling be utilized and then aggregated to the regional scale if possible. A prime example is the Northern Powder River Coal EIS in the discipline of economics/demographics. The region itself involved five counties, four of which were in Montana, the fifth in Wyoming (Northern Powder River Basin Coal, Montana, Final EIS 1980).

The Coal Town Model, developed by George Temple and Lloyd Bender at Montana State University, was used to analyze each county. The county-specific results were then aggregated to the regional level to depict not only the impact of the proposed actions on each county, but to demonstrate the total regional impacts. However, it should be noted that not all models can be aggregated to the regional level. Aggregation of site-specific models to regional scales is most effective if mining "clusters" exist--that is, mines located in spatial proximity to each other. A good example of this type of cluster exists in the Decker mining area in Montana. Areas such as Colstrip, Montana, mining blocks lend themselves well to modeling in the disciplines of hydrology and air quality (Bender et al. 1982).

Systems Analysis and EIS Objectives

The objectives of any EIS are multifaceted in scope. Although many EISs are specifically tailored to meet legal requirements, EISs should perform a number of functions besides the fulfillment of legal mandates. If the criteria outlined below are systematically met, the EIS process becomes ongoing and provides the public and decisionmaker with a useful document that withstands critical review and the passage of time (Wilson 1981).

Five criteria that an EIS should meet are:

1. Decision-making Document--This is the first and foremost criterion of an EIS. The mandates of NEPA and CEQ regulations must be met. Furthermore, in many EISs, local and State requirements must be met. Most State requirements are similar to the Federal acts; however, the public scoping and time frames may vary to some extent. The EIS author should check the varying requirements depending on the nature of the EIS and the location for which it's being written.

2. Reference Document--Not only should the EIS document be used as a decision-making tool, but the EIS researcher should design it to serve as a basic reference document. The reference aspect of the EIS helps the public learn about a given area and the related environmental, social, and economic problems. It should serve as a building block for future EISs.

If a systematic approach is taken in preparing the document, it need not be encyclopedic in scope. Vital and concise information can be compiled for all facets of the EIS including the proposed action, the effected or existing environment, and the impact and mitigation sections. As new forms of development occur in the area, the fundamental information analyzed in the original document can be used and expanded upon.

All EISs should be well documented empirically. A prime example of reference documents is progammatic EISs which analyze new areas with hypothetical types of development. Another type of reference EIS document is the regional analysis, in which proposed site-specifics, along with ongoing industrial and mining activities, are reviewed. The Northern Powder River Basin Coal EIS is an excellent example of this type of EIS. No decision as such was made from this EIS, but the EIS is a widely read document due to its reference attributes.

3. Planning Document--One of the most important characteristics of a properly prepared EIS is its influence is shaping industrial and mine plans to conform to environmental requirements. Not only are the impacts discernable through the EIS process, but the mitigating measures that effect changes in the mine plan should accompany them. If it is found that certain adverse impacts, such as sodic seeps, will result from a mine, the mine plan can be altered to mitigate the problem. The Spring Creek site-specific EIS prepared for the Decker mine is a good example. The company had to change its original proposal to ameliorate the sodic soils by burying the toxic materials at a greater depth than originally proposed.

By using a systems approach to long-range environmental problems, the author can begin to understand how a proposed action will impact an environment over many years. A large mine with a long mine life can be analyzed with some degree of accuracy if the proper data are collected and projected into the future.

In mining, particulary strip mining, hydrology is the foremost problem encountered by the EIS author. By using integrated and dynamic surface and groundwater models, future consequences can be perceived prior to the actual mining itself. As a picture of the future is portrayed through the systems approach, mitigation measures can be taken to safeguard reclamation at the mine site and agricultural properties around the mine. A good systems analysis is particularly useful for long-term mines that exist in critical agricultural areas in the semiarid mining regions of the West.

4. Disclosure Document--Since EISs cover many aspects of the social and physical environment, and only certain aspects can be acted upon by the regulatory agencies, other critical areas that might be adversely influenced by drastic social and economic change should be analyzed by the researcher. Once this information is reviewed and incorporated into the EIS, it should be made clear to the public in layman's terms. It is the EIS that informs the public of the magnitude or significance of economic and social impacts. Only when

local planners have a clear understanding of these kinds of impacts can they make proper decisions to effect changes within the community. Local governments can require impact assistance money from either the State or the corporations themselves.

Sociologists and economists have been using systems analysis perhaps longer than other researchers. A multitude of economic and demographic models have been developed over the years and have been used in many EISs. Many of these models, some of which will be cited later, have been used and validated in the coal regions of the Powder River Basin. They serve as prime examples of how, once built, models can be perfected as new EISs are written about a given area. They provide the decisionmaker with a fairly accurate description of the future and also help the public plan for its future.

5. Research Document--Since EISs are essentially critical reviews of proposed actions and existing environments with accompanying mitigating measures, research is imperative. All issues should be properly researched and scientifically documented. Research, if properly performed, will enhance the EIS as a reference document and also add to the body of evironmental knowledge. If the EIS is researched and catalogued in the data retrieval system, the information can be used to further advantage in the continuum of EISs.

MODELING TECHNIQUES AND METHODOLOGIES

Economic/Demographic Models

Probably the most extensive modeling has been done with economic and demographic data. This is not to say that E/D analysis is the most important aspect of EISs. It is to say that they have been used widely to attempt to understand growth in rural communities.

These models can provide vital information about current and future population, fiscal, and general economic growth due to a proposed action. Planners can use this information to ensure that public services are adequate to meet the anticipated growth. It also gives the local community an opportunity to decide how it wants to shape its future. In fact, communities near developing coal mines in Wyoming have begun to work with the coal companies to help shape their future rather than to simply react to the impacts of development.

A comprehensive catalog of models and model evaluation has been assembled by the U.S. Geological Survey in a recent publication titled Socioeconomic Forecasting Methodologies: A State-of-the-Art Review. The review is primarily concerned with evaluating 23 models through a ranking system of designed criteria, which include:

- The internal logic of each model.

- Are the right variables accounted for and systematically dealt with--i.e., does an employment driven population model also consider migration that is not employment related?

- The scale of inquiry--models specified at the county or multicounty level will be of little use in solving community-specific problems.

- The number of topics covered by each model--some models deal primarily with population or employment, whereas others get into more narrow and specific areas, such as demand for housing or fiscal impacts.

- The reasonableness of data demands--some very sophisticated models have great intellectual appeal but only limited utility because they demand data more comprehensive than anything available.

- The strength of documentation--i.e., are procedures clearly presented or is there a "black box" element that might make the model difficult to implement?

A list of these models evaluated is presented below (they are not ranked according to model characteristics or quality)(Socioeconomic Forecasting Methodologies: A State-of-the-Art Review 1981).

THE MODELS (Model Name, Year of Publication, if available)

BATTELLE I, 1977: A Demographic Model for Assessing the Socioeconomic Impacts of Large-Scale Industrial Development Projects
BATTELLE II, 1978: Socioeconomic and Demographic Forecasting Model
BOOM I, 1976: User's Guide to the Boom I Model
BOOMH, 1978: A Simulation Model for Boom Town Housing
BOOMP, 1978: Boomp User's Guide
BREAM, 1978: Economic/Demographic Assessment Manual
CLIPS, 1979: Community-Level Impacts Projection System
COALTOWN I,: An Introduction to the Coaltown Impact Assessment Model
COALTOWN II: A Dynamic Economic Systems Community Impact Model Applied to Coal Development in the Northern Great Plains
DEISM, 1978: Neveda's Demographic and Economic Impact Simulation Model
DRI, 1979: Socioeconomic Impacts of Westeren Energy Resource Development
EPA, 1978: Action Handbook: Managing Growth in the Small Community
MASS, 1978: Montana Population Projections, 1980-2000 for Counties and Incorporated Cities and Towns
MRMI, 1980: The Framework of the Multiregional, Multi-industry Forecasting Model
NED: The Navajo Economic-Demographic Model: A Method for Forecasting and Evaluating Alternative Navajo Economic Futures (Volume I)
POCS: POCS Reference Paper No. IV: Onshore Economic and Water Quality Impact Analysis of Proposed OCS Sale No. 48
PRB, 1979: System Dynamics Simulation Modeling Applied to Western Coal Development Environmental Impact Analysis

REAP I, 1978: The Reap Economic-Demographic Model-I: User Manual
REAP II, 1978: Reap Economic-Demographic Model: Technical Description
SEAM I, 1976: A Framework for Projecting Employment and Population Changes Accompanying Energy Development, Phase I
SEAM II, 1978: Summary Description of Seam: The Social and Economic Assessment Model
SIA, 1978: Socioeconomic Impact Assessment: A Methodology Applied to Synthetic Fuels
TAMS, 1979: The Texas Assessment Modeling System: User Manual
WRC: Wyoming Research Corporation: Regional Economic Model
UPED 79, 1980: Report on Revisions of the Utah Process Economic and Demographic Impact Model (UPED)

The EIS researcher and author should use this type of model handbook as a guide when selecting a specific forecasting model to do a certain environmental assessment. No one model can cover the needs of all EISs; it is essential that the proper model is picked to do a specific job.

All the parameters of the EIS should be carefully considered prior to model selection. Using the theoretical framework presented earlier in the paper will help the researcher pick the correct model.

Air Quality and Climate Models

Air quality and climate models have undergone a great deal of revision in the last decade as a result of widespread enactment of air quality legislation designed to curb atmospheric pollution. Air quality models are built to simulate the existing environment and then project into the future given the parameters of the existing environment plus any additional pollution. Many models have been built by and for the EPA to gain a better understanding of the dynamic forces that alter the atmosphere. Not only are models desiged to measure particulate movements and levels, but also much more subtle pollution problems, such as SO_2 levels.

With the enactment of the Clean Air Act of 1976, it has become increasingly important to gain a better understanding of spatial-temporal atmospheric changes relative to industrial, commercial, and residential air quality problems. In the Alton EIS, for example, the degradation of the atmosphere was simulated to illustrate various levels of air pollution as hypothetical power plants were added to the environment. With this type of simulation, the public can begin to understand the impacts as higher levels of industrialization are introduced to an area containing very popular national parks and natural scenery.

In the Northern Powder River Basin Coal EIS, the air quality was modeled to show the effects of the two existing coal-fired generators plus two additional power plants at Colstrip. Most of this modeling was undertaken by members of the Environmental Studies Program at the University of Montana under a contract with the U.S. Geological Survey. The work was extremely important because Colstrip has been designated a "non-attainment" area. Essentially, this is an area where sufficient air quality improvements must be established before any new pollution can be added. Again, by using a systems analysis approach, an understanding of the past, present, and future environment was gained by the public.

Below are listed some of the models currently available to the EIS researcher. The list is by no means exhaustive, but it will assist in the initial scoping of the EIS to determine the best model for a particular evaluation.

1. AIR QUALITY DISPLAY MODEL (AQDM)

Reference: TRW Systems Group "Air Quality Display Model" Prepared for National Air Pollution Control Administration, DHEW, U.S. Public Health Service, Washington, D.C., November, 1969 (NTIS PB 189194).

Abstract: AQDM is a climatological steady-state Gaussian plume model that estimates annual arithmetic average sulfur dioxide and particulate concentrations at ground level in urban areas. A statistical model based on Larsen is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

2. APRAC - 1A

Reference: Mancuso, R.L. and Ludwig, F.L., "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program", Publication No. EPA-650/3-73-001 (NTIS PB 213091), Environmental Protection Agency, Research Triangle Park, North Carolina, September, 1972.

Abstract: APRAC-1A is a model which computes hourly average carbon monoxide concentrations for any urban location. The model calculates contributions from dispersion on various scales: extraurban, from sources upwind of the city of interest; intraurban, from freeway, arterial, and feeder street sources; and local, from dispersion within street canyon. APRAC requires an extensive traffic inventory for the city of interest.

3. CLIMATOLOGICAL DISPERSION MODEL (CDM)

Reference: Busse, A.D. and Zimmerman, J.R., "User's Guide for the Climatological Dispersion Model", Publication No. EPA-RA-73-024 (NTIS PB 227346/AS), Environmental Protection Agency, Research Triangle Park, North Carolina, December, 1973.

Abstract: CDM is a climatological steady-state Guassian plume model for determining long-term (seasonal or annual arithmetic average pollutant concentration at any ground level receptor in an urban area. An expanded version (CDMQC) includes a statistical model based on Larsen to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

4. GAUSSIAN PLUME MULTIPLE SOURCE AIR QUALITY ALGORITHM (RAM)

Reference: Turner, D.B. and Novak, J.H., "User's Guide for RAM", Environmental Protection Agency, Research Triangle Park, North Carolina, 1978.

Abstract: RAM is a steady-state Saussian plume model for estimating concentrations of relatively stable pollutants for averaging times from an hour to a day from point and area sources. Level or gently rolling terrain is assumed. Calculations are performed for each hour. Both rural and urban versions are available.

Equations: The area source contributions are determined using the narrow-plume hypothesis similar to applications by Gifford and Hanna Contribution. The contribution is from a single upwind area source.

5. SINGLE SOURCE (CRSTER) MODEL

Reference: Environmental Protection Agency, "User's Manual for Single Source (CRSTER) Model", Publication No. EPA-450/2-77-013, (NTIS PB 271360), Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, July, 1977.

Abstract: CRSTER is a steady-state Gaussian plume technique applicable to both rural and urban areas in uneven terrain. The purpose of the technique is (1) to determine the maximum concentrations for certain averaging times between one hour and 24 hours, over a 1-year period due to a single point source of up to 19 stacks, (2) to determine the meteorological conditions which cause the maximum concentrations, and (3) to store concentration information useful in calculating frequency distributions for various averaging times. The concentration for each hour of the year is calculated and midnight-to-midnight averages are determined for each 24-hour period.

6. TEXAS CLIMATOLOGICAL MODEL

Reference: Porter, R.A. and Christiansen, J.H., "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board", Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, VA., September, 1976.

Christiansen, J.H. and Porter, R.A., "User's Guide to the Texas Climatological Model", Texas Air Control Board, Austin, TX., May, 1976.

Abstract: The TCM is a climatological model that predicts long-term arithmetic mean concentrations of nonreactive pollutants from point sources and area sources.

7. TEXAS EPISODIC MODEL

Reference: Porter R.A., and Christiansen, J.H., "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board", *Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling*, Airlie House, VA., September, 1976.

Christiansen, J.H. and Porter, R.A., "User's Guide to the Texas Episodic Model", Texas Air Control Board, May, 1976.

Abstract: The Texas Episodic Model (TEM) is a short-term (10-minute to 24-hour averaging time) Gaussian Plume Model for prediction of concentrations of nonreactive pollutants due to up to 300 elevated point sources and up to 200 area sources. Concentrations are calculated for 1 to 24 scenarios of meteorological conditions, averaging time, and mixing height (Guidelines on Air Quality Models 1978).

Hydrologic Models

The most critical area in any mining/environmental assessment is the hydrologic impact. By statute, hydrologic impacts must be given site-specific and cumulative treatment. Because hydrology is such a difficult area to analyze, it is imperative that the process be undertaken systematically and quantitatively. To date this has been difficult due to the lack of data available for a systems approach and the expense involved in modeling and data collection. However, legal and political pressure from public interest groups have pushed the hydrologic EIS evaluation process to a point in which a systems approach must be undertaken on all existing and projected mining operations.

The following is a brief evaluation of models currently available to analyze hydrologic problems. The list is by no means complete, but it does introduce the EIS researcher to a wide range of hydrologic models:

HYMO	Models surface water run-off, HYMO transforms rainfall data into run-off hydrographs and routes them through selected reaches.
HYFLOD	Calculates flood flow magnitude for 2-, 10-, 25-, 50-, and 100-year floods for Montana. Could also be used for Wyoming if the Craig/Rankl/Loutian method is added.

USGS Two-Dimensional Finite Difference Groundwater Flow Model--simulates in two dimensions the response of an aquifer to an imposed stress. The aquifer can be artesian, water table, or a combination of both and may be heterogeneous, anisotropic, and have irregular boundaries. Input includes transmissivity, storage coefficient, recharge and discharge. Output is expressed as a drawdown or potentiometric head.

USGS Three-Dimensional Finite Difference Groundwater Flow Model--this program is structurally similar to the 2-D model; the third dimension is developed by coupling a two-dimensional groundwater flow model with terms that represent flow through intervening confining beds, and data that account for vertical changes in transmissivity and storage.

MINEPAK A Computer software system for mine plan exploration and development. There is a separate FACT SHEET discussing the system in detail.

STORM This program can be used to simulate the impact of changes in land use by predicting the water quality of surface run-off. It will also provide preliminary sizing of storage and treatment facilities required to provide control of the storm water run-off.

AQUIFEM I Two-Dimensional Finite Element Groundwater Flow Model--simulates in two dimensions the response of an aquifer to an imposed stress. Capabilities are similar to the Finite Difference Flow Model; additional capabilities include seasonal expression of evapotranspiration and pumping, and expression of leakage to or from streams for a defined reach of a stream course. In this approach, fewer nodes are required to represent the aquifer, thus reducing the cost.

SDF This program calculates the depletion of a stream from pumping an alluvial aquifer.

GLOVER A code that calculates stream depletion over time due to aquifer stress using Glover's second approximation.

CONFUSE Code to calculate crop consumptive uses over time using Blaney-Criddle method.

WATEQF Code to calculate the equilibrium distribution of inorganic aquatic species of major and important minor elements in natural waters.

WQRRS This package consists of six programs: three simulation programs and three supplementary programs to analyze and display output.

1. Stream Water Quality--evaluates water quality conditions in a stream network of branching channels.

2. Stream Hydraulics Package--evaluates velocity, flow, and depth at intervals in a stream network.

3. Reservoir Quality--evaluates water quality conditions in a reservoir.

4. Water Quality Profile--plots simulated water quality versus river mile.

5. Water Quality Statistics--performs statistical analysis of simulated water quality data at a certain point in a stream.

6. Water Quality Plot--plots water quality concentrations versus time at a particular point in a stream.

HEC I Flood Hydrograph Package--This program consists of six parts:

1. Basin Rainfall--run-off and snowmelt computation.

2. Unit graph and hydrograph computation.

3. Unit graph and loss rate optimization.

4. Hydrograph combining and routing.

5. Streamflow routing and optimization.

6. Balanced hydrograph.

HEC-1 Dam Safety Analysis--This program is an extension of HEC I to include an evaluation of the overtopping potential of a dam during a storm. It is capable of estimating the downstream hydrologic consequences resulting from an assumed structural failure of a dam.

HEC-2 Water Surface Profiles--Water surface profiles are computed for steady, gradually varied flow in rivers of any cross section. Flow may be subcritical or supercritical, and flow through structures can be modeled. River cross sections and computed water surface elevations can be plotted.

HEC-5 Simulation of Flood Control and Conservation Systems--This program simulates the sequential operation of a system of reservoirs of any configuration. It can be used to determine flood control and conservation storage requirements of reservoirs, the influence of reservoirs on run-off in a basin, the evaluation of operational criteria for flood control and conservation damages, systems costs, and system net benefits for flood damage reduction.

HEC-6 Scour and Depletion in Rivers and Reservoirs--Reeves/Duquid two-dimensional finite element Hydrodynamic and Mans Ion transfer model.

INJPRE A code developed to predict the probable rate of pressure increase in an injection reservoir from a proposed injection operation.

GRWAT A two-dimensional finite difference model for groundwater flow that uses a Gaussian elimination scheme for the motion solution.

SEEP Finite element numerical model for solving steady-state problems of free surface or confined flow of groundwater in a two-dimensional or axisymmetric porous region (flow net analysis).

HP-SWEM HYDROPAC Surface Water Erosion model simulates rainfall run-off relationships, determines basin erosion and sedimentation rates, and determines if pre- and post-mining topography is hydrologically stable.

Electrical sensitivity analysis programs include:

RESIST A program to yield theoretical apparent sensitivity values from a specific layered earth model.

INVERSE A program to yield a possible layered earth model from field measurements of apparent sensitivity.

The list of hydrology models is from Ertec, Inc. of Golden, Colorado, a consulting firm that specializes in mining and environmental analyses. Ertec, Inc. maintains a comprehensive library of computer programs to support the analysis and interpretation of hydrologic field data.

Other Models in the Physical and Life Sciences

Modeling in other disciplines can be applied using the same basic forecasting methodologies that are used in social/economics, air quality, and hydrology. The control variables are not as stable in other areas, such as wildlife and vegetation. It is more difficult to obtain information for wildlife, at least over the long term, to make a modeling exercise meaningful and accurate. This is particularly true when big game species are studied, as in the example of grizzly bear populations. A necessary data base coupled with a predictable outcome simply doesn't exist in many cases. Additionally, exogenous factors that have impacting characteristics are very difficult to dynamically integrate into the modeling effort. An example would be the secondary impact on a large game population over time and space resulting from an expanding miner hunting population. This is particularly true when a series of mines would come on line in a relatively short period. It becomes highly speculative to place a number on how many deer, grouse, or other types of animals will be impacted and to what extent.

Demand Versus Export Base Model

Most modeling in the mining EISs has assumed a relative degree of demand for the mineral or fuel. Essentially, this means that the model is a function of supply. In the case of EISs, supply simply is the level of production. The production will determine the level of employment, the amount of taxes, secondary population impacts, and ultimately the entire outcome of the impact analyses. In essence, the demand for production is assumed to be a given and the supply will eventually ensue once conditions such as permitting and environmental obstacles are overcome. Approaching any EIS from this perspective is certainly axiomatic if all the parameters within the model are accurate; however, it does preclude the possibility of realistic demand for the mineral and fuel.

A step that has become more popular in recent EISs is to examine the need or demand for the mineral or fuel prior to constructing an export-based model. In doing a demand analysis the model can create a supply parameter that rids itself of speculation. The demand analysis in effect creates its own supply.

Export-based models are merely tools to be used to explore potential future impacts. The EIS researcher should be cautioned against using modeling that has no basis in demand logic. If realistic demand for a commodity is not established, a guide from which future impacts are derived cannot offer realistic environmental impact analysis. The supply and significance of impacts will determine the timing and level of extraction of coal (or mineral and/or fuels). The initial supply is a function of demand for the commodity.

Demand modeling is critical to long-term understanding of any area under consideration for development. Prior to any prediction made about impacts, a detailed study should be made of what need exists for the mineral or fuel. Only then can a supply model be constructed commensurate with demand. In the past, particularly during the early stages of the energy crisis, many researchers looked at the ability of an area to supply minerals or fuel. Unfortunately, all this did was confuse and mislead the public and the decisionmakers. It did eventually prompt the development of better techniques for modeling, but for a time it only heightened the crisis atmosphere of the energy and mineral shortage. This tended to cloud the real issues of what fuels and minerals needed to be developed and for what period to alleviate the crisis at hand.

Within the last few years, more attention has been given to designing realistic demand models. A case in point has been the effort made by Arnold Silverman, John Duffield, and Tom Coefield to determine the level of need for Montana coal over time. Only after establishing this need, or demand, can supply scenarios be generated to match the level of demand. By following this procedure, much speculation can be eliminated (Duffield and Silverman 1982).

Interdisciplinary Models

Interdisciplinary models that cover all disciplines are nearly impossible to build. Most models do have the ability to look at various impact analyses by combining subsets or routines of models. The currently used social and economic models examine a range of impacts, such as taxes and fiscal effects on an area. However, the model is basically confined to social sciences in a very narrow range. Sociological issues such as quality of life are left to empirical surveys.

In the early stages of modeling and environmental work (1975), attempts were made to analyze all aspects of potential impacts in a synergistic fashion. Inputs such as political, physical, human, and environmental were integrated into the model. The models became so expensive and complex and full of data gaps that they were abandoned for more simplistic models that dealt with only a few problems. Since the mid-70's very few models have tried to encompass every possible impact conceivable. Although the models have been refined technically, they have also become more discipline-specific.

APPLIED SYSTEMS ANALYSIS IN MONTANA EIS DOCUMENTS

Montana has been using modeling analyses in their coal environmental impact statements since 1971. Most of the early systems analysis was incorporated into the Spring Creek EIS, a site-specific document explaining the effects of mining on the existing Spring Creek Mine located just north of the West Decker Mine. The early attempts were difficult to undertake and used the social/economic model, Coal Town I. The most difficult problem was to assess the impacts of spill-over population into the Sheridan, Wyoming area. Most of the workers would live in Sheridan County and commute to the Spring Creek Mine. After many revisions of the model and careful utilization of cross-State and county tax problems, the model was run and reasonable results were obtained. The model results were validated after the mine was put into operation. Although it was the first attempt to integrate modeling into the Montana EIS process, it did pave the way for future modeling to be used. A critical view could be taken of modeling in terms of fine-tuning various parts of the Coal Town I simulation mode. Many parameters needed to be adjusted, such as the mine-specific capital labor ratios. It became readily apparent that each mine and county needed special attention and that no generic approach was applicable to all the coal mines in southeastern Montana (Proposed Mining and Reclamation Plan, Spring Creek Mine FEIS 1979).

Perhaps the most interesting problem confronting Montana EISs was finding an appropriate method to apply systems analysis to the Montana Regional Coal EIS. Since the Coal Town model is essentially county-specific, each county within the region had to be studied as a specific entity, and then all the counties (Sheridan, Wyoming, Big Horn, Custer, and Powder River) had to be aggregated into a regional perspective. By modeling the entire region, the modellers and EIS team members were given a chance to collect, analyze, and project the process of five counties interacting in a dynamic fashion.

The Coal Town I model was eventually upgraded to a series of revised models designated Coal Town V. The new model was used in various site-specific EISs ranging from the Peabody Coal EIS to Westmoreland's Absoloka Mine expansion. By using the same modeling method throughout a series of coal mine EISs in essentially the same region, the EIS authors and Coal Town modelers were able to validate and improve the modeling technique to a point where a great deal of knowledge was gained about each county in the study area and the associated effects of coal mining.

Recently, different models have been applied to Montana EISs. The Northern Cheyenne Tribe used the West Model, a derivative of the Montana Mass Model, to analyze the effects of the proposed Montco Mine near Ashland, Montana. Mountain West of Billings used another model to analyze the direct effects of the Montco Mine and associated development. This model essentially depicts the fiscal, demographic, and economic impacts that will evolve if the Montco Mine is constructed. Much like the Coal Town modeling analyses, it looks at subregional impacts of a multitude of mines that will be triggered if the Montco Mine if built. The hypothesis is that if one pivotal mine is constructed, such as Montco, at least four to five other mines must be constructed in the adjacent areas to pay for the Tongue River Railroad. The approach used in Mountain West's Bream Model systematically captures the effects of mining spatiotemporally.

Attempts are currently being made to model the hydrologic effects of mining at Colstrip, Montana. Because approximately 22,000 acres are planned for mining at Colstrip over the next 40 years, a methodology must be developed to analyze short-term, long-term, and cumulative impacts on the hydrologic regime of the area. By applying a series of modeling approaches to the hydrologic structure, it is hoped that a clear perception will be gained about mining at Colstrip. A systems approach allows the EIS researcher to better understand the baseline information and to make a fair prediction of how it will behave over the next 40 years.

Montana has taken a step forward in integrating a systems approach into its EISs. Not only has a better, more systematic understanding been gained of the social and physical environment, but a more precise methodology has been developed for producing timely and cost-effective EISs. The systems approach gives each EIS an analysis around which a meaningful narrative can be built.

INTEGRATING MINE PLANS THROUGH THE SYSTEMS ANALYSIS APPROACH

Since a mine plan is a logical blueprint for developing and operating a mine, it would seem appropriate that the environmental work necessary to make the mine plan comply with State and Federal regulation would be a system also. By using a systematic approach to attain environmental compliance, the EIS researcher will quickly gain a better understanding of each mine plan in relationship to environmental goals and problems. Baseline data can be gathered and the appropriate gaps can be filled. Furthermore, where necessary, modeling approaches can be used in the cases of air quality, hydrology, and social/economic evaluations.

If a mining company has legal nonattenuated rights to mine and all the environmental constraints are complied with, the mining company should have the right to mine. It is then the obligation of the EIS author to find the optimal mine plan by working with the mining corporation to allow maximum profit and also to find the optimal environmental constraints. By systematically changing mine plans to conform to environmental regulations, both the mining company and the regulators can find a mine plan that fits State and corporate needs.

A case in point is the EIS prepared by the Montana Department of State Lands on the dump expansion for the Berkeley Pit at Butte, Montana. Certain goals needed to be attained, such as guaranteeing that the dump site would be reclaimed. By altering the plan to conform to the environmental regulations, it was discovered after several attempts that the dump site could be reclaimed in a manner that was economically acceptable. Because the Anaconda Copper Company had developed a systems approach to its mine, it was relatively simple to alter the mine plan to allow for compliance to environmental regulations.

Government regulations and corporate goals should work so that permitting is accomplished and a profit can be made by the company. Only by having a system that can adapt to the needs of industry can the regulatory bodies meet their goals and the goals of the corporate structure.

Although systems analysis is expensive at the outset, over the long run it will pay for itself through quality output and reduction in duplication. Once a system is developed, it can be used recurrently by making minor adjustments. This has been the case with the MSU Coal Town model and Mountain West's Bream model. By using this approach, the long-run costs of doing environmental work are reduced both for the State and the corporation.

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THE PLANT INFORMATION NETWORK (PIN) IN RESOURCE PLANNING AND DECISIONMAKING

by

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INTRODUCTION

The Plant Information Network (PIN) is a computerized information storage and retrieval system designed to provide information for land and resource management questions. It was adapted and modified from a previous information system called RAPIC (Rapid Access Plant Information Center), which was developed at Colorado State University. Major uses at this time are providing information for vegetation inventories, impact assessments, rare plant conservation and protection, and planning and design of reclamation projects. Approximately 5,000 native or naturalized vascular plant species found in Colorado, Montana, North Dakota, Utah and Wyoming are included in PIN. Advantages of the data bank are: (1) information can be continuously curated and kept up-to-date; (2) accessibility is easy and convenient and can be nearly instantaneous with interactive terminals; (3) information may be retrieved in any combination of attributes; (4) information gaps can be identified and the chance of new information being lost is reduced; and (5) the expense of obtaining information is reduced compared to conventional methods.

In 1975 RAPIC was recognized as a potential tool for land use managers and other people making decisions and needing information about plant species and vegetation. A new project was initiated in 1976 which included the basic concepts of the RAPIC system and greatly expanded its geographical coverage and its informational base; the name of the system was then changed to PIN.

The objective of the PIN system is to provide information about plant species and vegetation to land use planners and resource managers quickly and inexpensively. PIN is not intended to replace field work; it is only a tool for cataloging information that is often unavailable or inaccessible. The development of PIN will help field biologists better prepare for vegetation studies and help resource managers make more knowledgeable decisions.

Sources of information included in PIN are: (1) herbarium specimen labels from major herbaria in each of the States; (2) extensive searches through scientific, professional, and popular publications pertaining to the taxonomy, geography, biology, ecology, and economics of the plants found in the three States; and (3) the unpublished judgment and experience of experts and field researchers on the attributes and utility of plants in the areas of relations of plants and wildlife, livestock, soil, and man.

Three majors uses of PIN were anticipated and are now resulting from the system, which include: (1) vegetation inventories (lists of species found in any county of the States can be queried from the system), (2) environmental assessment and impact analysis (economic and ecologic value of species are recorded in the system and can be queried and used for anticipating the effects of disturbances or land use changes), and (3) reclamation planning (queries can be constructed to obtain lists of plants adapted to site conditions and having desirable characteristics to fulfill reclamation objectives).

INFORMATION AVAILABLE

The basic level of information entry in the system is by species (or sometimes subspecies or variety). The species recorded as present in the data base are the ones for which there are vouchered specimens collected and on file in seven herbaria, which are the herbaria at: Colorado State University, University of Colorado Museum, Rocky Mountain at the University of Wyoming, Montana State University, University of Montana, North Dakota State University, and the Utah State University. Currently, information on approximately 5,000 plant species has been entered in the system.

The characteristics or attributes recorded for each plant species are called "descriptors," which are grouped for convenience into five categories, representing taxonomic, geographical, biological, economic, and ecological information. At present there are over 500 descriptors in the system, including over 280 in the taxonomic, biolobical, economic, and ecological categories. The remaining descriptors are the county distributions of the species. Each descriptor is divided into mutually exclusive subsets or ratings called "descriptor states." (See Appendix A for descriptors and descriptor state definitions.)

Care must be exercised in interpreting the results of a PIN query. Where possible, definitions were used that are commonly accepted in the plant ecology, range science, and revegetation fields of expertise. However, because the descriptor states must be mutually exclusive, this was not always possible. In these cases, working definitions as noted in Appendix A were used. A brief list and summary of some of these descriptors follows. This list includes descriptors that will be of most interest or those which may cause some confusion or misinterpretation.

Taxonomic

The taxonomic descriptors include the division, family, genus, species, infraspecific, and common names for each of the species in the system. Most of this taxonomic information came from State floras and botanical literature. The infraspecific names are varieties or subspecies. The common names came from a ranked order of references. The first reference used was Plummer *et al*. (1977), the Intermountain Range Plant Names and Symbols. If Plummer did not have a common name for the species in PIN, then *Standardized Plant Names* by Kelsey and Dayton (1942) was used. If neither of these sources had a common name, then Beetle's (1970) *Recommended Plant Names* was used. Additional literature was surveyed if none of these references listed a common name.

Geographic

The geographic descriptors include origin, counties, and minimum and maximum elevations at which the vouchered collections of a plant species have been found in each of the States. The county information is at two levels of reliability. A county "present" record means that the species has a vouchered specimen collected and stored in one of the herbaria listed above. A county "reported" record means that a reliable source has reported the species' occurrence in that county, but to our knowledge there are no specimens of the plant in the above herbaria.

Biological

The biological category of descriptors includes anthesis, carbon dioxide fixation, habit, life cycle, reproduction, and trophic status. Anthesis is the time of flowering (for angiosperms) or pollination (for gymnosperms). The anthesis descriptors include beginning of anthesis (month), anthesis (mode month), and end of anthesis (month) for each State. Habit is the growth form or outward appearance of the plants, such as grasslike, tree, or shrub. The life cycle descriptors include perennial, biennial, annual, and all combinations of these lifespans. The reproduction descriptors include the sexual or asexual processes by which plants generate others of the same kind. The descriptor states for reproduction include sexual, vegetative, apomictic, and all combinations of these three reproductive modes.

Ecological and Economic

The above descriptors and descriptor states have been completed for the 5,000 species, if the information was available in documented sources. Because of the immensity of the task to develop the information base of ecological and economic descriptors for this many species, a subset of approximately 850 "important" species was chosen having high economic, ecological, or biological values (such as importance to grazing resources, wildlife populations, or as rare, threatened or endangered plants) reclamation value, or predominance in the five-State area. Most of the ecological and economic descriptor information was completed only for these "important" species.

The ecological categories of plant descriptors include the relative dominance of the species in 32 different vegetation types found in the five-state area. These vegetation types are taken from Kuchler (1964) and are the vegetation types he mapped for the States included in PIN. Each species is ranked as dominant, subdominant, or a component for each one of these vegetation types.

Also included in the ecological descriptors are disturbance and soil chemistry indicators, growth relationships of the species on textural classes of soils, habitat or moisture conditions under which a plant grows, the degree of slope on which the plant is normally found, the optimum soil depth on which the plant normally obtains the best growth, mycorrhizal relationship, nodule-forming and nitrogen-fixing information, potential biomass production by State, and population dynamics, including endemic species and rareness by State and species stability or the relative vulnerability of the species to extinction as determined by Federal and State authorities. The Federal status is determined from the latest available USDI Fish and Wildlife Service lists published in the Federal Register. State status is determined from State natural heritage programs, native plant societies, or local botanists.

The economic category of descriptors include allergenic; edible; culture; erosion control potential by State; establishment requirements by State; short-term and long-term revegetation potential by State; weediness; energy value; protein value; cover and food values for various classes of wildlife by State; palatability for cattle, sheep, horses by State; and poisonous to livestock.

The establishment descriptor includes high, medium, and low and the relative extent of cultural practices which must be employed to insure successful species planting.

The revegetation potential descriptor, including high, medium, and low, is the ability of a plant to become established and persist on sites to which it is adapted.

The culture descriptor is a text descriptor. Text descriptors are included in PIN in a narrative format and are retrieved in narrative form. The culture descriptor includes information such as seeds-per-unit weight, seed maturity, methods of cleaning and collection, seed treatments, germination requirements, planting practices, habitat adaptations, and propagation recommendations. As you would expect, this information is much more complete for some species than others.

PIN EXAMPLE QUERIES

The above description of the Plant Information Network (PIN) relates the basic concepts behind development of the system, describes the major intended uses of the system, and relates the major uses of the system to date.

As examples of these uses, PIN queries were prepared to illustrate the major types of queries and many of the other characteristics of the PIN system.*

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*For example printouts, write to the authors at: U.S. Fish and Wildlife Service, Western Energy and Land Use Team, 2625 Redwing Road, Ft. Collins, Colorado 80526

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APPENDIX A.

PIN DESCRIPTORS AND DESCRIPTOR STATE DEFINITIONS

APPENDIX A. PIN DESCRIPTORS AND DESCRIPTOR STATE DEFINITIONS

Taxonomic

The classification of plants into the following appropriate categories:

1. DIVISION--A nonscientific category of the major vascular plant groups.

   a. Conifer--(Gymnospermae) a member of a group of predominantly evergreen and cone-bearing trees.
   b. Dicot--(Dicotyledoneae) one of the two major divisions of angiosperms, characterized by a pair of embryonic seed leaves.
   c. Monocot--(Monocotyledoneae) one of the two major divisions of angiosperms, characterized by a single embryonic seed leaf.
   d. Fern allies--(Lydcopodiophyta, Equisetophyta, Polypodiophyta) vascular plants not producing seeds or true flowers, reproducing by spores.

2. FAMILY--A name category ranking below an order and above a genus, with the ending "-aceae."

3. GENUS--A name category ranking below a family and above a species. The use of the genus followed by a Latin adjective or epithet forms the scientific name of a plant.

4. SPECIES--The lowest, most commonly used category of taxonomic classification, ranking below a genus.

5. INFRASPECIFIC--A morphologically recognizable category of classification ranking below a species. Refers to subspecies, varieties, or forms.

6. COMMON NAME--The colloquial epithet in general usage and language of the inhabitants of a geographic region.

Geographic

The attributes of a plant which pertain to a specific region.

7. ORIGIN--The geographic area to which a plant is indigenous.

   a. Native--Any plant known to be indigenous to Colorado, Montana, North Dakota, Utah, or Wyoming. The descriptor state, "native," takes precedence over the descriptor state, "North America."
   b. North America--The descriptor state, "North America," takes precedence over all other geographic descriptors except "native."
   c. Africa
   d. Asia
   e. Australia-Pacific
   f. Eurasia
   g. Europe
   h. South America

8. COUNTIES--Each county name is a descriptor and must be asked for specifically. Each county name ends with "-CO, -MT, -ND, -UT, or -WY" to designate Colorado, Montana, North Dakota, Utah, or Wyoming, respectively. Includes all counties for Colorado (63), Montana (56), North Dakota (53), Utah (29), and Wyoming (24). Each county descriptor uses the following descriptor states:

a. Present--The plant is known to occur in the county based on a specimen of the plant being deposited and verified in one of the following herbaria: Colorado State University, Fort Collins, CO; University of Colorado, Boulder, CO; U.S. Forest Service Herbaria, Fort Collins, CO; Montana State University, Bozeman, Mt; University of Montana, Missoula, MT; North Dakota State University, Fargo, ND; Utah State University, Logan, UT; and Rocky Mountain Herbarium, Laramie, WY.

b. Reported--The plant has been reported in the county, but there was no specimen of it in the herbaria listed above when surveyed. Reported records are generally obtained from reliable literature citations.

9. MAXIMUM ELEVATION-CO--The highest elevation at which a plant has been collected in Colorado. Recorded in 100-foot intervals from 3,000 to 15,000 feet.

10. MAXIMUM ELEVATION-MT--The highest elevation at which a plant has been collected in Montana. Recorded in 100-foot intervals from 1,500 to 13,000 feet.

11. MAXIMUM ELEVATION-ND--The highest elevation at which a plant has been collected in North Dakota. Recorded in 100-foot intervals from 800 to 3,500 feet. Elevation data for North Dakota are not currently in the data bank.

12. MAXIMUM ELEVATION-UT--The highest elevation at which a plant has been collected in Utah. Recorded in 100-foot intervals from 2,000 to 14,000 feet.

13. MAXIMUM ELEVATION-WY--The highest elevation at which a plant has been collected in Wyoming. Recorded in 100-foot intervals from 3,000 to 14,500 feet.

14. MINIMUM ELEVATION-CO--The lowest elevation at which a plant has been collected in Colorado. Recorded in 100-foot intervals from 3,000 to 15,000 feet.

15. MINIMUM ELEVATION-MT--The lowest elevation at which a plant has been collected in Montana. Recorded in 100-foot intervals from 1,500 to 13,000 feet.

16. MINIMUM ELEVATION-ND--The lowest elevation at which a plant has been collected in North Dakota. Recorded in 100-foot intervals from 800 to 3,500 feet. Elevation data for North Dakota are not currently in the data bank.

17. MINIMUM ELEVATION-UT--The lowest elevation at which a plant has been collected in UTAH. Recorded in 100-foot intervals from 2,000 to 14,000 feet.

18. MINIMUM ELEVATION-WY--The lowest elevation at which a plant has been collected in Wyoming. Recorded in 100-foot intervals from 3,000 to 14,500 feet.

Biologic

The attributes of a plant which pertain to its own life processes.

Anthesis--The time of flowering for angiosperms, or pollination of gymnosperms, in Colorado, Montana, North Dakota, Utah, or Wyoming. Anthesis is determined for most angiosperms from herbarium specimens. Manuals are used to determine anthesis time for a few angiosperms (including grasses, sedges, and rushes) because they are seldom collected when in flower and for gymnosperms because pollination cannot be directly observed. Descriptors for three different anthesis times are provided: 1) the earliest observed month of anthesis, or "beginning of anthesis"; 2) the most frequently observed month of anthesis, or "mode anthesis"; and 3) the latest observed month of anthesis, or "end of anthesis." All anthesis descriptors (19-33) use the following descriptor states:

a. January
b. February
c. March
d. April
e. May
f. June
g. July
h. August
i. September
j. October
k. November
l. December

19. BEGINNING OF ANTHESIS-CO
20. BEGINNING OF ANTHESIS-MT
21. BEGINNING OF ANTHESIS-ND
22. BEGINNING OF ANTHESIS-UT
23. BEGINNING OF ANTHESIS-WY

24. MODE OF ANTHESIS-CO
25. MODE OF ANTHESIS-MT
26. MODE OF ANTHESIS-ND
27. MODE OF ANTHESIS-UT
28. MODE OF ANTHESIS-WY

29. END OF ANTHESIS-CO
30. END OF ANTHESIS-MT
31. END OF ANTHESIS-ND
32. END OF ANTHESIS-UT
33. END OF ANTHESIS-WY

34. CARBON DIOXIDE FIXATION--The biochemical and physiological mechanism associated with the incorporation of CO_2 and its ultimate conversion into carbohydrates.

  a. C_3--The plant uses a pathway where the first step in CO_2 fixation involves the formation of three-carbon compounds, the stomata are opened, and CO_2 is fixed in the daylight.

  b. C_4--The plant uses a pathway where the first step in CO_2 fixation involves the formation of four-carbon compounds, the stomata are opened, and CO_2 is fixed in the daylight.

  c. CAM (crassulaceous acid metabolism)--The plant uses a pathway where the first step in CO_2 fixation involves the formation of four-carbon compounds, the stomata are opened, and CO_2 is fixed in the dark.

  d. Other--The plant uses another type of pathway (e.g., is intermediate between C_3 and C_4 plants).

  e. None--The plant does not fix CO_2 (i.e., non-green parasitic or saprophytic plants).

35. HABIT--The growth form or outward appearance of a plant.

  a. Tree--A woody plant that usually produces one main trunk or bole and a more or less distinct and elevated head.
  b. Shrub-tree--A plant whose growth form may be either that of a shrub or tree.
  c. Shrub--A woody plant that remains low and produces several shoots or trunks from the base.
  d. Liana--A woody plant with elongate, flexible, non self-supporting stems.
  e. Vine--A nonwoody plant with elongate, flexible, non self-supporting stems.
  f. Forb--A nonwoody plant with a self-supporting stem whose aboveground parts die each year and is not grasslike. Includes half-shrubs or plants woody only at the very base.
  g. Grasslike--Nonwoody plants belonging to the grass, sedge, or rush families.

35. LIFE CYCLE--The series of stages in form and mode of life which an organism exhibits between successive recurrences of a certain primary stage.

a. Perennial--The plant grows for 3 or more years.
b. Biennial--The plant grows for 2 years from seed to maturity to death.
c. Annual--The plant grows for one year from seed to maturity to death.
d. Perennial-biennial--The plant has the potential for growth as either a perennial or a biennial.
e. Biennial-annual--The plant has the potential for growth as either a biennial or an annual.
f. Perennial-annual--The plant has the potential for growth as either a perennial, biennial, or an annual.

37. REPRODUCTION--The sexual or asexual process by which a plant generates others of the same kind.

a. Sexual--The plant reproduces by pollination and fertilization.
b. Vegetative--All cases where structures such as bulbils, tubers, stolons, rhizomes, etc., which are normally accessory means of reproduction, take over the whole reproductive processes of a plant.
c. Apomictic--The plant has a type of reproduction which results in the formation of seeds and embryos by a nonsexual process.
d. Vegetative-sexual--The plant reproduces vegetatively and sexually.
e. Sexual-apomictic--The plant reproduces sexually and apomicticly.
f. Vegetative-sexual-apomictic--The plant reproduces vegetatively, sexually, and apomicticly.
g. Vegetative-apomictic--The plant reproduces vegetatively and apomicticly.

38. TROPHIC STATUS--A plant's method of nutrient procurement.

a. Autotrophic--The plant is capable of self-nutrition; can use carbon, nitrogen, and sulfur in organic combinations and obtain energy from the sunlight.
b. Parasitic--The plant lives on and/or in other living organisms and obtains some or all of its nutrients from the host.
c. Saprophytic--The plant lives on and/or in dead organic material and obtains nutrients from it.
d. Symbiotic--The plant lives in close association with another plant and the symbionts derive nutritional requirements from each other.

Ecologic

The attributes of a plant which pertain to its relationship to community structure and function, environment and population dynamics.

Relative Dominance--The proportional influence of a plant within each of the vegetation zones listed below. Each zone is a descriptor and must be asked for separately. Vegetation zones (except disturbed areas) as defined by Kuchler (1964). Descriptors 39-69 use the following states:

a. Dominant--A plant, which by means of its number, coverage, or size, has major influence upon the environmental conditions within the vegetation type.
b. Subdominant--A plant, which by means of its number, coverage or size, has a moderate influence upon the environmental conditions within the vegetation type.
c. Component--A plant species present in the vegetation type but not a dominant or subdominant.

39. ALPINE MEADOWS/BARREN

40. WESTERN SPRUCE-FIR FOREST

41. SW SPRUCE-FIR FOREST(SW = Southwestern)

42. SPRUCE-FIR-DOUGLAS FIR FOREST

43. DOUGLAS FIR FOREST

44. PINE-DOUGLAS FIR FOREST

45. BLACK HILLS PINE FOREST

46. WESTERN PONDEROSA FOREST

47. EASTERN PONDEROSA FOREST

48. ARIZONA PINE FOREST

49. NORTHERN FLOODPLAIN FOREST

50. JUNIPER-PINYON WOODLAND

51. MOUNTAIN MAHOGANY-OAK SCRUB

52. GREAT BASIN SAGEBRUSH

53. SALTBUSH-GREASEWOOD

54. BLACKBRUSH

55. CREOSOTE BUSH

56. DESERT

57. SAGEBRUSH STEPPE

58. WHEATGRASS-NEELDEGRASS SHRUBSTEPPE

59. GALLETA-THREE AWN SHRUBSTEPPE

60. FOOTHILLS PRAIRIE

61. SANDSAGE-BLUESTEM PRAIRIE

62. WHEATGRASS-NEEDLEGRASS

63. GRAMA-NEEDLEGRASS

64. GRAMA-NEEDLEGRASS-WHEATGRASS

65. GRAMA-BUFFALOGRASS

66. WHEATGRASS-BLUESTEM-NEEDLEGRASS

67. WHEATGRASS-BLUEGRASS

68. OAK SAVANNA

69. NEBRASKA SANDHILLS PRAIRIE

70. TULE MARSHES

71. DISTURBED AREAS--A plant which occurs on areas of significant environmental disruption.

    a. Component--The plant occurs on disturbed areas during one or more of the early stages in natural revegetation through processes of secondary succession.
    b. No--The plant does not normally occur on disturbed areas.

72. DISTURBANCE INDICATOR--A plant whose growth and distribution commonly indicates one of the following types of disturbance in Colorado, Montana, North Dakota, Utah, or Wyoming. Indicators are only scored once in the order of precedence shown.

    a. Erosion--The accelerated wearing away of rocks and soils at the earth's surface by natural processes.
    b. Mechanical--The physical disturbance of the soil and vegetation by trampling of man or animals, or by machinery.
    c. Overgrazing--Excessive feeding by domestic or wild animals.
    d. Fire--Disturbance by burning.
    e. Other--Indicates a disturbance not listed (e.g., flooding or poor drainage).
    f. No--The presence of the plant does not indicate a disturbance.

73. SOIL CHEMISTRY INDICATOR--A plant whose growth and distribution commonly (80% of the time or more) indicates the presence of one of the following unusual soil characteristics in Colorado, Montana, North Dakota, Utah, or Wyoming.

a. Boron--Soils with boron-containing minerals such as borax, sassolite, ulexite, colemanite, boracite, tourmaline.
b. Gypsum--Soils which contain hydrous calcium sulfate.
c. Selenium--Soils which contain selenium or selenids such as clausthalite.
d. Serpentine--Soils which contain hydrous magnesium silicate, an indication of a magnesium-calcium imbalance.
e. Acidic--Soil pH less than 6.
f. Saline plus sodic--Alkaline soils which are saline, sodic, or sodic-saline.
g. Other--Other unusual soil characteristics may be indicated. User should consult expert.
h. None--Plant does not indicate any unusual soil chemistry characteristics.

Growth on Soils--The relative ability of a plant to show the full development of all phases of its growth potential on a particular soil texture or soil type where the plant normally occurs in Colorado, Montana, North Dakota, Utah, or Wyoming. Descriptors 74-133 use the following descriptor states:

a. Good--The plant is highly adapted to growth on a particular soil texture or soil type.
b. Fair--The plant is moderately adapted to growth on a particular soil texture or soil type.
c. Poor--The plant shows little or no adaptability to growth on a particular soil texture or soil type.

Growth on Gravel--A soil in which large particles (between 2 mm and 7.62 cm) make up 70% or more of the material by weight.

74. GROWTH ON GRAVEL-CO
75. GROWTH ON GRAVEL-MT
76. GROWTH ON GRAVEL-ND
77. GROWTH ON GRAVEL-UT
78. GROWTH ON GRAVEL-WY

Growth on Sand--A soil in which the sand separates (0.05-2 mm) make up 70% or more of the material by weight.

79. GROWTH ON SAND-CO
80. GROWTH ON SAND-MT
81. GROWTH ON SAND-ND
82. GROWTH ON SAND-UT
83. GROWTH ON SAND-WY

Growth on Sandy Loam--A loamy soil which is intermediate in texture between sand and loam.

84. GROWTH ON SANDY LOAM-CO
85. GROWTH ON SANDY LOAM-MT
86. GROWTH ON SANDY LOAM-ND
87. GROWTH ON SANDY LOAM-UT
88. GROWTH ON SANDY LOAM-WY

Growth on Loam--A soil which is considered to have an ideal texture for gardening. It contains about equal amounts of silt (0.002-0.05 mm) and sand, and less than 25% clay.

89. GROWTH ON LOAM-CO
90. GROWTH ON LOAM-MT
91. GROWTH ON LOAM-ND
92. GROWTH ON LOAM-UT
93. GROWTH ON LOAM-WY

Growth on Clay Loam--A loamy soil which is intermediate in texture between clay and loam.

94. GROWTH ON CLAY LOAM-CO
95. GROWTH ON CLAY LOAM-MT
96. GROWTH ON CLAY LOAM-ND
97. GROWTH ON CLAY LOAM-UT
98. GROWTH ON CLAY LOAM-WY

Growth on Clay--A soil which at least 35% clay separates (less than 0.002 mm) by weight but no more than 50%.

99. GROWTH ON CLAY-CO
100. GROWTH ON CLAY-MT
101. GROWTH ON CLAY-ND
102. GROWTH ON CLAY-UT
103. GROWTH ON CLAY-WY

Growth on Dense Clay--A soil with at least 50% clay separates (less than 0.002 mm) by weight.

104. GROWTH ON DENSE CLAY-CO
105. GROWTH ON DENSE CLAY-MT
106. GROWTH ON DENSE CLAY-ND
107. GROWTH ON DENSE CLAY-UT
108. GROWTH ON DENSE CLAY-WY

Growth on Organic Soils--A soil which contains more than 20% organic matter by weight.

109. GROWTH ON ORGANIC SOILS-CO
110. GROWTH ON ORGANIC SOILS-MT
111. GROWTH ON ORGANIC SOILS-ND (data not available for ND)
112. GROWTH ON ORGANIC SOILS-UT
113. GROWTH ON ORGANIC SOILS-WY

Growth on Acidic Soils--A soil with a pH less than 6.

114. GROWTH ON ACIDIC SOILS-CO
115. GROWTH ON ACIDIC SOILS-MT
116. GROWTH ON ACIDIC SOILS-ND (data not available for ND)
117. GROWTH ON ACIDIC SOILS-UT
118. GROWTH ON ACIDIC SOILS-WY

Growth on Saline Soils--An alkaline soil with a conductance of saturation extract exceeding 4 mmho/cm but with sodium comprising less than 15% of the absorbed cations and pH of less than 8.5.

119. GROWTH ON SALINE SOILS-CO
120. GROWTH ON SALINE SOILS-MT
121. GROWTH ON SALINE SOILS-ND
122. GROWTH ON SALINE SOILS-UT
123. GROWTH ON SALINE SOILS-WY

Growth on Sodic Soils--An alkaline soil with both a pH of 8.5 or higher and exchangeble sodium content of 15% or more but with conductance of saturation extract less than 4 mmho/cm.

124. GROWTH ON SODIC SOILS-CO
125. GROWTH ON SODIC SOILS-MT
126. GROWTH ON SODIC SOILS-ND
127. GROWTH ON SODIC SOILS-UT
128. GROWTH ON SODIC SOILS-WY

Growth on Sodic-Saline Soils--An alkaline soil with both conductance of saturation extract exceeding 4 mmho/cm and exchangeable sodium content of 15% or more but with a pH of less than 8.5.

129. GROWTH ON SODIC-SALINE SOILS-CO
130. GROWTH ON SODIC-SALINE SOILS-MT
131. GROWTH ON SODIC-SALINE SOILS-ND
132. GROWTH ON SODIC-SALINE SOILS-UT
133. GROWTH ON SODIC-SALINE SOILS-WY

134. HABITAT--The type of locality or set of ecological conditions under which a plant grows, defined here in terms of the moisture requirements of the plant.

a. Dry--The plant grows in soil that is characterized by conditions of extended periods of soil drought.
b. Dry-moist--The plant may grow in either dry or moist habitats.
c. Moist--The plant grows in soil that is characterized by conditions of medium soil moisture.
d. Moist-wet--The plant may grow in either moist or wet habitats.
e. Wet--The plant grows in soil that is saturated with water. Includes plants which are occasionally emergent aquatics during periods of excessively high water levels.

f. Dry-moist-wet--The plant may grow in dry, moist, or wet habitats.
g. Emergent aquatic--The plant grows in a fresh water environment with its vegetation parts floating upon or rising above the water surface.
h. Submerged aquatic--The plant grows in a fresh water environment with its vegetation parts floating upon or rising above the water surface.
i. Phreatophytic--The plant derives its water supply from the water table and its growth is more or less independent of short-term rainfall. If the water table is essentially at the soil surface during most of the growing season, the plant is scored as a wet habitat plant rather than a phreatophyte.
j. Epiphytic--The plant grows upon another living plant. It may or may not obtain nutrients from the host. For this distinction, see descriptor 38, TROPHIC STATUS.

Growth on Slopes--The capability of a plant to grow naturally on gentle (0-8%), moderate (9-30%), or steep (31+%) slopes in Colorado, Montana, North Dakota, Utah, or Wyoming. Descriptors 135-138 use the following descriptor states:

a. Good--Plant frequently occurs on indicated slope.
b. Fair--Plant occasionally occurs on indicated slope.
c. Poor--Plant rarely or never occurs on indicated slope.

135. GROWTH ON GENTLE SLOPES

136. GROWTH ON MODERATE SLOPES

137. GROWTH ON STEEP SLOPES

138. OPTIMUM SOIL DEPTH--Depth of soil to parent material on which a plant normally produces best growth in Colorado, Montana, North Dakota, Utah, or Wyoming. Measured in inches.

a. 0-10--Very shallow
b. 10-20--Shallow to medium
c. 20+--Deep

139. MYCORRHIZAL RELATIONSHIPS--The nature of the relationship of a plant to a mycorrhizal association. All plants listed as being mycorrhizal have been cited in the literature as such. It should be recognized that most plants are considered to be mycorrhizal, but published reports are available for only a few at the present time.

a. Endomycorrhizal--Mycorrhizal association having a loose network of fungal hyphae enclosing the root and intracellular hyphae penetrating the cortical cells of the root.

b. Ectomycorrhizal--Mycorrhizal association having a dense fungal sheath enclosing the root and intercellular hyphae penetrating the root cortex.

c. Ectendomycorrhizal--Mycorrhizal association having a dense fungal sheath enclosing the root and both inter- and intracellular hyphae penetrating the root cortex.

d. Endo/ecto--Refers to plants reported as being both endomycorrhizal and ectomycorrhizal.

e. Ecto/ectendo--Refers to plants reported as being both ectomycorrhizal and ectendomycorrhizal.

f. Nonmycorrhizal--Refers either to plants that have been examined for mycorrhizae with none found, or plants that occur in families considered to be classically nonmycorrhizal (Aizoaceae, Amaranthaceae, Brassicaceae, (Cruciferae), Caryophyllaceae, Chenopodiaceae, Commelinaceae, Cyperaceae, Fumariaceae, Juncaceae, Nyctaginaceae, Polygonaceae, and Urticaceae). Thus, the plants are probably nonmycorrhizal, although exceptions may be found in the future.

140. NODULE-FORMING--Occurrence of root nodules on a plant's roots.

a. Reported--Reported as nodule-forming by observation or in the literature.

b. Possible--May form root nodules but no literature citation has been found.

c. No--Reported as not nodule-forming in literature.

141. NITROGEN FIXING--A plant that can assimilate and fix the free nitrogen of atmosphere with the aid of microorganisms.

a. Yes--Plant fixes nitrogen, as reported in the literature.

b. Maybe--The plant may fix nitrogen but has not been reported as such in the literature.

c. No--Plant is known not to fix nitrogen.

Potential Biomass Production--The relative genetic ability of a plant to produce plant material by weight on an annual basis compared to other members of the same life form (a grass is rated against other grasses, etc.). Species are rated as if growing on the sites where they are typically found in Colorado, Montana, North Dakota, Utah, or Wyoming. Thus, a plant may have a higher or lower biomass production than the rating given by PIN if it occurs on a site more favorable or less favorable than its normal site. Descriptors 142-146 use the following descriptor states:

a. High--Plant possesses ability to produce a greater yield of dry plant material than most other species of the same life form. Examples of high-producing species of different life forms are big bluestem (Andropogon gerardii), smooth brome (Bromus inermis

inermis), alfalfa (*Medicago sativa*), yellow sweetclover (*Melilotus officinalis*), big sagebrush (*Artemisia tridentata*), snowbrush ceanothus (*Ceanothus velutinus*), Englemann spruce, (*Picea engelmannii*), and plains cottonwood (*Populus deltoides occidentalis*).

b. Medium--Plant produces an average yield of dry plant material as compared to other species of the same life form. Examples of medium-producing species of different life forms are timothy (*Phleum pratense*), Kentucky bluegrass (*Poa pratensis*), common sunflower (*Helianthus annuus*), alsike clover (*Trifolium hybridum*), shadscale (*Atriplex confertifolia*), western snowberry (*Symphoricarpos occidentalis*), limber pine (*Pinus flexilis*), and inland boxelder (*Acer negundo*).

c. Low--Plant produces a low yield of dry plant material as compared to other species of the same life form. Examples of low-producing species of different life forms are Sandberg bluegrass (*Poa sandbergii*), cheatgrass brome (*Bromus tectorum*), northern bedstraw (*Galium boreale*), broom snakeweed (*Gutierrezia sarothrae sarothrae*), leadplant (*Amorpha canescens*), bearberry (*Arctostaphylos uva-ursi*), and creeping juniper (*Juniperus horizontalis*).

d. Very low--Plant produces a very low yield of dry plant material as compared to other species of the same life form. Examples of very low-producing species of different life forms are ring muhly (*Muhlenbergia torreyi*), sixweeks fescue (*Vulpia octoflora*), harebell (*Campanula rotundifolia*), Hoods phlox (*Phlox hoodii*), cushion coryphantha (*Coryphantha vivipara*), and bristlecone pine (*Pinus aristata*).

142. POTENTIAL BIOMASS PRODUCTION-CO
143. POTENTIAL BIOMASS PRODUCTION-MT
144. POTENTIAL BIOMASS PRODUCTION-ND
145. POTENTIAL BIOMASS PRODUCTION-UT
146. POTENTIAL BIOMASS PRODUCTION-WY

147. ENDEMIC-CO--A plant whose distribution is restricted to Colorado or Colorado and adjacent states. Descriptor states are self-explanatory. Abbrevations used are as follows: AZ=Arizona; CO=Colorado; KS=Kansas; MT=Montana; NE=Nebraska; NM=New Mexico; OK=Oklahoma; UT=Utah; WY=Wyoming.

a. Colorado
b. CO-KS
c. CO-KS-OK
d. CO-NE
e. CO-NM
f. CO-NM-AZ
g. CO-NM-OK
h. CO-OK
i. CO-UT
j. CO-UT-AZ

k. CO-UT-NM
l. CO-UT-NM-AZ
m. CO-WY
n. CO-WY-MT
o. CO-WY-NE
p. CO-WY-NM
q. CO-WY-UT
r. No--Plant is not endemic to Colorado or one of the regions listed above.

148. ENDEMIC-MT--A plant whose distribution is restricted to Montana or Montana and adjacent states or Canadian provinces. Descriptor states are self-explanatory. Abbreviations used are as follows: ALTA=Alberta, Canada: BC=British Columbia, Canada; CO=Colorado; ID=Idaho; MT=Montana; NV=Nevada; OR=Oregon; SD=South Dakota; UT=Utah; WA=Washington; WY=Wyoming.

a. Montana
b. MT-ALTA
c. MT-ALTA-BC
d. MT-ID
e. MT-ID-ALTA
f. MT-ID-NV
g. MT-ID-OR
h. MT-ID-WA
i. MT-WY
j. MT-WY-CO
k. MT-WY-ID
l. MT-WY-SD
m. MT-WY-UT
n. No--Plant is not endemic to Montana or one of the regions listed above.

149. ENDEMIC-ND--A plant whose distribution is restricted to North Dakota or North Dakota and adjacent states or Canadian provinces. Descriptor states are self-explanatory. Abbreviations used are as follows: MAN=Manitoba, Canada; MN=Minnesota; MT=Montana; ND=North Dakota; SASK=Saskatchewan, Canada; SD=South Dakota.

a. North Dakota
b. ND-MAN
c. ND-MN
d. ND-MT
e. ND-SASK
f. ND-SD
g. No--Plant is not endemic to North Dakota or one of the regions listed above.

150. ENDEMIC-UT--A plant whose distribution is restricted to Utah or Utah and adjacent states. Descriptor states are self-explanatory. Abbreviations used are as follows: AZ=Arizona; CO=Colorado; ID=Idaho; NV=Nevada; WY=Wyoming.

a. Utah
b. UT-AZ
c. UT-CO
d. UT-ID
e. UT-NV
f. UT-WY
g. No--Plant is not endemic to Utah or one of the regions listed above.

151. ENDEMIC-WY--A plant whose distribution is restricted to Wyoming or Wyoming and adjacent states. Descriptor states are self-explanatory. Abbreviations used are as follows: CO=Colorado; ID=Idaho; MT=Montana; NE=Nebraska; NM=New Mexico; OR=Oregon; SD=South Dakota; UT-Utah; WY=Wyoming.

a. Wyoming
b. WY-CO-NE
c. WY-CO-NM
d. WY-CO-UT
e. WY-ID
f. WY-ID-OR
g. WY-MT
h. WY-MT-CO
i. WY-MT-ID
j. WY-MT-SD
k. WY-MT-UT
l. WY-UT
m. WY-UT-ID
n. No--Plant is not endemic to Wyoming or one of the regions listed above.

Rare--A plant which has a small population in its range in Colorado, Montana, North Dakota, Utah or Wyoming. It may be found in a restricted geographic region (5% of the counties of the respective state or less) or it may occur sparsely over a wider area. Descriptors 152-156 use the following descriptor states:

a. Yes--The plant is rare in the state.
b. No--The plant is not rare in the state.

152. RARE-CO
153. RARE-MT
154. RARE-ND
155. RARE-UT
156. RARE-WY

Species Stability--The relative vulnerability of a plant taxon (i.e., species, subspecies, variety, or form) to extinction as determined from Federal, State, or local listings.

a. Officially endangered--A plant taxon which has passed final rulemaking procedures and has been officially listed as endangered by the U.S. Congress under the Endangered Species Act. The plant is afforded legal protection because it is in danger of extinction throughout all or a significant portion of its range due to destruction or modification of habitat, overutilization or exploitation, disease, predation, or other natural or manmade factors.

b. Officially endangered--A plant taxon which has passed final rulemaking procedures and has been officially listed as threatened by the U.S. Congress under the Endangered Species Act. The plant is afforded legal protection because it is likely to become an endangered species in the foreseeable future throughout all or a significant portion of its range.

c. Proposed endangered--A plant taxon which has been proposed for endangered status in the Federal Register but has not yet completed final rulemaking procedures. The plant is afforded legal protection for a period of 2 years from the date of proposal during which it may be: 1) officially listed as endangered and gain permanent legal protection; 2) deemed not to merit endangered status and be voluntarily withdrawn from consideration; or 3) mandatorily removed from proposed status because no action has been taken within the required time limit.

d. Proposed threatened--A plant taxon which has been proposed for threatened status in the Federal Register but has not yet completed final rulemaking procedures. The plant is afforded legal protection for a period of 2 years from the date of proposal during which it may be: 1) officially listed as threatened and gain permanent legal protection; 2) deemed not to merit threatened status and be voluntarily withdrawn from consideration; or 3) mandatorily removed from proposed status because no action has been taken within the required time limit.

e. Candidate/category 1--A plant taxon under Federal consideration for proposed endangered or threatened status. Sufficient information is currently available to support publication of the plant as proposed endangered or threatened in the Federal Register. While no legal protection is afforded the plant until such a rule is published, the U.S. Fish and Wildlife Service recommends that it be given consideration in environmental planning. Some taxa included in this category may already be extinct.

f. Candidate/category 2--A plant taxon under Federal consideration for proposed endangered or threatened status. Existing information suggests that the plant merits proposed endangered or threatened status, but there is not yet sufficient data to support publication of a proposed rule in the Federal Register. While no legal protection is afforded the plant until such a rule is published, the U.S. Fish and Wildlife Service recommends that it be given consideration in environmental planning.

g. State sensitive--A plant taxon which local botanists and/or State organizations (e.g., natural heritage programs and native plant societies) consider to be unique and possibly meriting protection within a particular State because the plant is an endemic, a disjunct, reaches the limits of its geographic range within the state, and/or is in danger of extinction within the State. These plants have no current Federal legal status and may even be abundant in other states.

h. Presumed extinct/category 3A--A plant taxon originally proposed as endangered or threatened in the Federal Register but removed from consideration for this status because persuasive evidence exists of its extinction.

i. Invalid taxon/category 3B--A plant taxon originally proposed as endangered or threatened in the Federal Register but removed from consideration for this status because it does not meet the Endangered Species Act's definition of "species."

j. More abundand/category 3C--A plant taxon originally proposed as endangered or threatened in the Federal Register but removed from consideration for this status because subsequent research has shown it to be more abundant or widespread than previously believed and/or not subject to any identifiable threat. State-sensititive species have priority over this category.

157. SPECIES STABILITY-CO
158. SPECIES STABILITY-MT
159. SPECIES STABILITY-ND
160. SPECIES STABILITY-UT
161. SPECIES STABILITY-WY

Economic

The attributes of a plant which have either positive or negative monetary value.

Human Health and Nutrition

162. HAYFEVER CAUSING--Inducing a hayfever response in humans.

a. Yes--The plant is reported in the literature as causing hayfever.
b. Maybe--The plant is reported to possibly cause a hayfever response; thought to be hayfever causing but not yet proven so.
c. No--The plant is known to be definitely not hayfever causing in any circumstances and reported so in the literature

163. EDIBLE--A plant which can be eaten as food by humans.

a. Yes--One or more parts of the plant are edible.
b. Yes-qualified--The plant is edible only after a specific preparation or in certain seasons. User should consult expert.
c. No--The plant is not edible but not poisonous.
d. Poisonous--The plant contains toxic substances or potential toxic substances that would prove harmful if ingested.

Revegation Planting

164. CULTURE-- A textual description of the planting requirements of a species based upon a literature survey. Completeness of data for species varies with the amount of published literature available. Major topics covered include: 1) procurement--information concerning the collection or purchase of seed; 2) pretreatment--techniques for prolonging seed viability, overcoming seed dormancy, and enhancing rapid and complete seed germination; 3) laboratory germination--results of experimental germination of seeds under controlled conditions; and 4) cultural practices--recommendations for propagating the plant, including environmental requirements. All information presented is documented with literature citations. A bibliography of these citations is available upon request.

Erosion Control Potential--A plant which commonly exhibits growth habit, plant structure, biomass and/or root system that has the potential to reduce soil erosion in Colorado, Montana, North Dakota, Utah, or Wyoming. Descriptors 165-169 use the following descriptor states:

a. High--Plant that has aggressive growth habits, persistent plant structure, high potential biomass, and/or good soil-binding root-rhizome-runner system in established stands.
b. Medium--Plant that has moderately aggressive growth, moderately persistent plant structure, moderate potential biomass, and/or moderate soil-binding root-rhizome-runner system in established stands.
c. Low--Plant that has poor growth, persistence, biomass and/or soil-binding root system that makes it generally inadequate for erosion control.

165. EROSION CONTROL POTENTIAL-CO
166. EROSION CONTROL POTENTIAL-MT
167. EROSION CONTROL POTENTIAL-ND
168. EROSION CONTROL POTENTIAL-UT
169. EROSION CONTROL POTENTIAL-WY

Establishment Requirements--The relative extent of cultural practices which must be employed to insure a successful planting of the species on sites to which it is adapted in Colorado, Montana, North Dakota, Utah, or Wyoming. Descriptors 170-174 use the following descriptor states:

a. High--Species requires elaborate or intensive cultural practices (e.g., irrigation, special seed treatments, containerized seedlings).
b. Medium--Species requires standard tillage practices or special cultural practices of short duration (e.g., plowing and/or discing and drilling).

c. Low--Species requires only minimal cultural practices (e.g., pioneer or invader species).

170. ESTABLISHMENT REQUIREMENTS-CO
171. ESTABLISHMENT REQUIREMENTS-MT
172. ESTABLISHMENT REQUIREMENTS-ND
173. ESTABLISHMENT REQUIREMENTS-UT
174. ESTABLISHMENT REQUIREMENTS-WY

Short-term Revegetation Potential--The ability of a plant to become quickly established and exhibit rapid growth within 1 to 3 years (includes annuals) in Colorado, Montana, North Dakota, Utah, or Wyoming. Descriptors 175-179 use the following descriptor states:

a. High--Plant demonstrates rapid growth, good cover, and good reproduction.
b. Medium--Plant demonstrates moderately rapid growth, fair cover and fair reproduction.
c. Low--Plant demonstrates slow growth, poor cover, and poor reproduction.

175. SHORT TERM REVEGETATION POTENTIAL-CO
176. SHORT TERM REVEGETATION POTENTIAL-MT
177. SHORT TERM REVEGETATION POTENTIAL-ND
178. SHORT TERM REVEGETATION POTENTIAL-UT
179. SHORT TERM REVEGETATION POTENTIAL-WY

Long-term Revegetation Potential--The ability of a plant to become established and persist over a period of more than 3 years in Colorado, Montana, North Dakota, Utah, or Wyoming. Descriptors 180-184 use the following descriptor states:

a. High--Plant demonstrates good growth, cover, reproduction, and stand maintenance characteristics.
b. Medium--Plant demonstrates fair growth, cover, reproduction, and stand maintenance characteristics.
c. Low--Plant demonstrates poor growth, cover, reproduction, and stand maintenance characteristics.

180. LONG TERM REVEGETATION POTENTIAL-CO
181. LONG TERM REVEGETATION POTENTIAL-MT
182. LONG TERM REVEGETATION POTENTIAL-ND
183. LONG TERM REVEGETATION POTENTIAL-UT
184. LONG TERM REVEGETATION POTENTIAL-WY

185. WEEDINESS--A plant considered undesirable or troublesome, especially one that is growing where it is not wanted. Each plant is scored only once in the order of precedence.

a. Noxious--A plant which is listed on official noxious weed seed lists of Colorado, Montana, North Dakota, Utah, or Wyoming. The specific State or States in which a plant is considered noxious is indicated by a hypenated abbreviation at the end of the word "noxious" (e.g., noxious-CO indicates a noxious weed seed in Colorado; noxious-CO/MT indicates a noxious weed seed in Colorado and Montana, etc.).

b. Economic--A plant whose growth and reproduction cause economic loss. Has priority over colonizing.

c. Colonizing--A plant which has attributes enabling it to become easily established in areas of environmental disturbance or where it is not wanted.

d. Nonweedy--Not a weed.

Wildlife and Livestock

Cover Value--The degree to which a plant provides environmental protection, during one or more seasons (i.e., thermal, nesting, brooding or feeding cover, etc.) for wildlife species in Colorado, Montana, North Dakota, Utah, or Wyoming. Descriptors 186-225 use the following descriptor states:

a. Good--Readily utilized for cover when available.
b. Fair--Moderately utilized for cover when available.
c. Poor--Rarely or never utilized for cover when available.

186. ELK COVER VALUE-CO
187. ELK COVER VALUE-MT
188. ELK COVER VALUE-ND (data not available - no elk in ND)
189. ELK COVER VALUE-UT
190. ELK COVER VALUE-WY

191. MULE DEER COVER VALUE-CO
192. MULE DEER COVER VALUE-MT
193. MULE DEER COVER VALUE-ND
194. MULE DEER COVER VALUE-UT
195. MULE DEER COVER VALUE-WY

196. WHITETAIL DEER COVER VALUE-CO
197. WHITETAIL DEER COVER VALUE-MT
198. WHITETAIL DEER COVER VALUE-ND
199. WHITETAIL DEER COVER VALUE-UT
200. WHITETAIL DEER COVER VALUE-WY

201. ANTELOPE COVER VALUE-CO
202. ANTELOPE COVER VALUE-MT
203. ANTELOPE COVER VALUE-ND
204. ANTELOPE COVER VALUE-UT
205. ANTELOPE COVER VALUE-WY

206. UPLAND GAME BIRD COVER VALUE-CO
207. UPLAND GAME BIRD COVER VALUE-MT
208. UPLAND GAME BIRD COVER VALUE-ND
209. UPLAND GAME BIRD COVER VALUE-UT
210. UPLAND GAME BIRD COVER VALUE-WY

211. WATERFOWL COVER VALUE-CO
212. WATERFOWL COVER VALUE-MT
213. WATERFOWL COVER VALUE-ND
214. WATERFOWL COVER VALUE-UT
215. WATERFOWL COVER VALUE-WY

216. SMALL NONGAME BIRD COVER VALUE-CO
217. SMALL NONGAME BIRD COVER VALUE-MT
218. SMALL NONGAME BIRD COVER VALUE-ND
219. SMALL NONGAME BIRD COVER VALUE-UT
220. SMALL NONGAME BIRD COVER VALUE-WY

221. SMALL MAMMAL COVER VALUE-CO
222. SMALL MAMMAL COVER VALUE-MT
223. SMALL MAMMAL COVER VALUE-ND
224. SMALL MAMMAL COVER VALUE-UT
225. SMALL MAMMAL COVER VALUE-WY

Food Value--The relish and degree of use shown by a wildlife species for a plant or plant part, as well as the plant's availability throughout its range in Colorado, Montana, North Dakota, Utah, or Wyoming.

a. Descriptors 226-265 use the following descriptor states:

b. Good--Readily to moderately available in the plant's range and consumed to a high degree.
c. Fair--Readily to moderately available in the plant's range but consumed only to a moderate degree.
Poor--Available but the plant is consumed to only a small degree or not at all.

226. ELK FOOD VALUE-CO
227. ELK FOOD VALUE-MT
228. ELK FOOD VALUE-ND (data not available - no elk in ND)
229. ELK FOOD VALUE-UT
230. ELK FOOD VALUE-WY

231. MULE DEER FOOD VALUE-CO
232. MULE DEER FOOD VALUE-MT
233. MULE DEER FOOD VALUE-ND
234. MULE DEER FOOD VALUE-UT
235. MULE DEER FOOD VALUE-WY

236. WHITETAIL DEER FOOD VALUE-CO
237. WHITETAIL DEER FOOD VALUE-MT
238. WHITETAIL DEER FOOD VALUE-ND
239. WHITETAIL DEER FOOD VALUE-UT
240. WHITETAIL DEER FOOD VALUE-WY

241. ANTELOPE FOOD VALUE-CO
242. ANTELOPE FOOD VALUE-MT
243. ANTELOPE FOOD VALUE-ND
244. ANTELOPE FOOD VALUE-UT
245. ANTELOPE FOOD VALUE-WY

246. UPLAND GAME BIRD FOOD VALUE-CO
247. UPLAND GAME BIRD FOOD VALUE-MT
248. UPLAND GAME BIRD FOOD VALUE-ND
249. UPLAND GAME BIRD FOOD VALUE-UT
250. UPLAND GAME BIRD FOOD VALUE-WY

251. WATERFOWL FOOD VALUE-CO
252. WATERFOWL FOOD VALUE-MT
253. WATERFOWL FOOD VALUE-ND
254. WATERFOWL FOOD VALUE-UT
255. WATERFOWL FOOD VALUE-WY

256. SMALL NONGAME BIRD FOOD VALUE-CO
257. SMALL NONGAME BIRD FOOD VALUE-MT
258. SMALL NONGAME BIRD FOOD VALUE-ND
259. SMALL NONGAME BIRD FOOD VALUE-UT
260. SMALL NONGAME BIRD FOOD VALUE-WY

261. SMALL MAMMAL FOOD VALUE-CO
262. SMALL MAMMAL FOOD VALUE-MT
263. SMALL MAMMAL FOOD VALUE-ND
264. SMALL MAMMAL FOOD VALUE-UT
265. SMALL MAMMAL FOOD VALUE-WY

Palatability--The relish and degree of use shown by livestock for a plant or plant part in Colorado, Montana, North Dakota, Utah or Wyoming. Descriptors 266-280 use the following descriptor states:

a. Good--Highly relished and consumed to a high degree.
b. Fair--Moderately relished and consumed to a moderate degree.
c. Poor--Not relished and normally consumed to only a small degree or not at all.

266. CATTLE FORAGE PALATABILITY-CO
267. CATTLE FORAGE PALATABILITY-MT
268. CATTLE FORAGE PALATABILITY-ND
269. CATTLE FORAGE PALATABILITY-UT
270. CATTLE FORAGE PALATABILITY-WY

271. SHEEP FORAGE PALATABILITY-CO
272. SHEEP FORAGE PALATABILITY-MT
273. SHEEP FORAGE PALATABILITY-ND
274. SHEEP FORAGE PALATABILITY-UT
275. SHEEP FORAGE PALATABILITY-WY

276. HORSE FORAGE PALATABILITY-CO
277. HORSE FORAGE PALATABILITY-MT
278. HORSE FORAGE PALATABILITY-ND
279. HORSE FORAGE PALATABILITY-UT
280. HORSE FORAGE PALATABILITY-WY

281. ENERGY VALUE--The usable energy a plant provides to livestock or wildlife during the period from flowering or early seed formation to the following spring, within a comparable life form (a grass is compared to other grasses, etc.) in Colorado, Montana, North Dakota, Utah, or Wyoming.

a. High--Retains usable energy value well during fall and winter (cures well and/or retains leaves, etc.).
b. Medium--Retains usable energy value well during fall and winter.
c. Low--Poor retention of usable energy value well during fall and winter (cures poorly and/or drops leaves, etc.).

282. PROTEIN VALUE--The digestible protein a plant provides to livestock or wildlife during the period from flowering or early seed formation to the following spring, within a comparable life form (a grass is compared to other grasses, etc.) in Colorado, Montana, North Dakota, Utah, or Wyoming.

a. High--Retains digestible protein value well during fall and winter (cures well and/or retains leaves, etc.).
b. Medium--Retains digestible protein value well during fall and winter.
c. Low--Poor retention of digestible protein value during fall and winter (cures poorly and/or drops leaves, etc.).

283. POISONOUS-LIVESTOCK--Plants that contain or produce under natural conditions physiologically active or toxic substances in sufficient amounts to cause harmful effects in livestock or produce mechanically injurious plant parts. Each plant is included in only one category in the order of precedence shown.

a. Major--A plant that typically produces substances of high toxicity, may be highly or moderately palatable, and is usually availabe in its range. This category includes plants that often accumulate selenium or molybdenum or nitrates to toxic levels. Plants in this category cause the majority of livestock losses.

b. Minor--A plant that produces substances of low toxicity and/or rarely produces substances of high toxicity, and/or has low palatability, and/or is usually unavailable or rare in its range. This category includes plants that are secondary selenium or molybdenum accumulators. It should be noted that also included in this category are legumes, crop plants, and other species of significant economic value that rarely cause toxicosis or bloat and then only under unusual conditions of weather, local abundance of the plants, animal hunger, etc. Careful management will usually alleviate these problems.

c. Mechanical injury--A plant that produces a mechanically injurious plant part during some part of the growth cycle.

d. Suspected--A plant of suspected but not confirmed toxicity. This category includes some plants that are suspect because there are known toxic species in the same genus.

e. No--A plant believed to be nontoxic.

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The volumes include a broad range of largely technical papers on surface coal mining in the Northern Great Plains. Topics of the papers range from characterization of the coal resource to reclamation planning opportunities and socioeconomic analysis of coal resource development. Papers were presented at coal development workshops conducted in Casper, Wyoming, and Grand Junction, Colorado, under the sponsorship of the Bureau of Land Management.

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